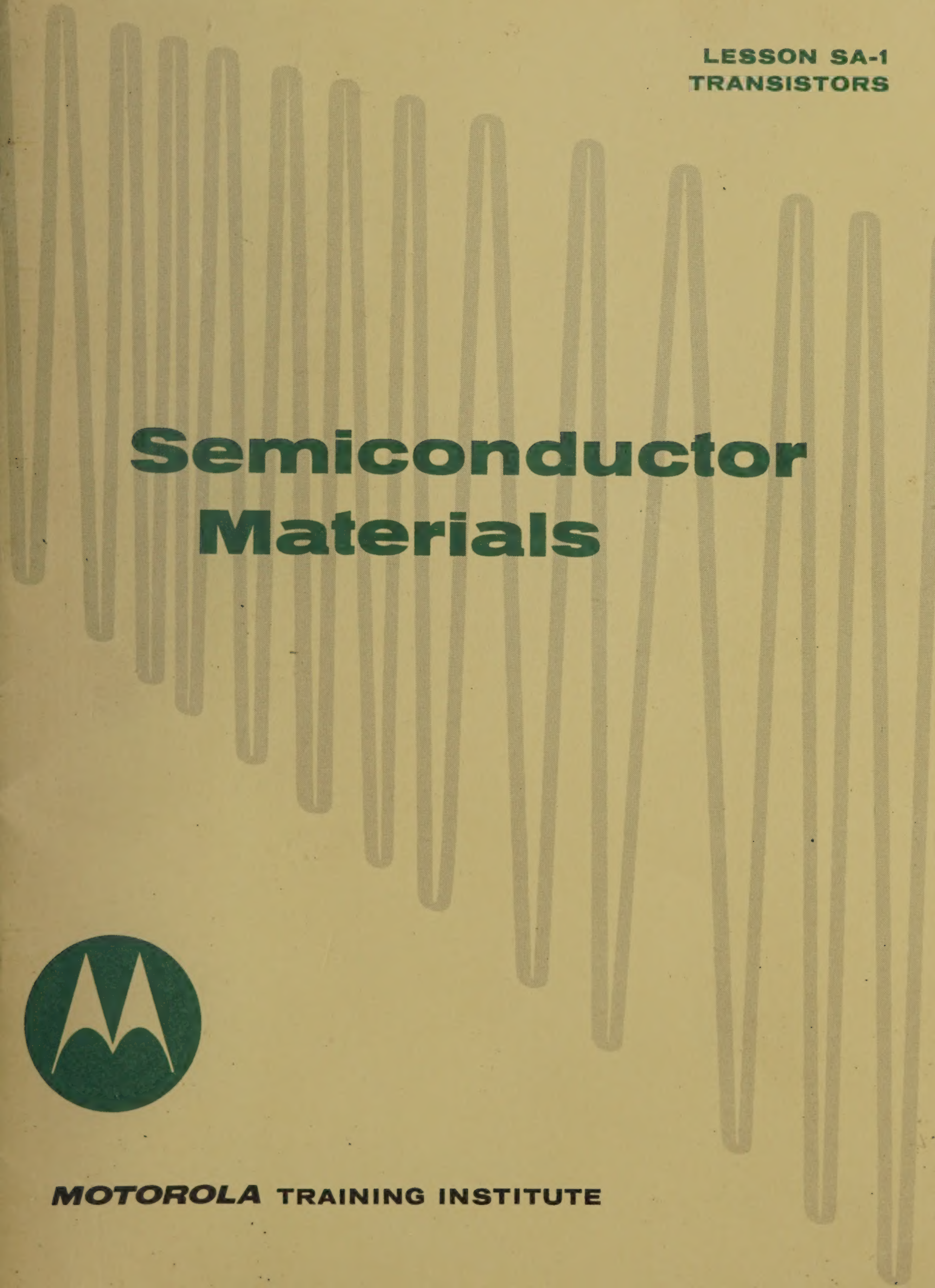
MOTOROLA TRAINING INSTITUTE

TWO-WAY RADIO COMMUNICATIONS

A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON SA-1
TRANSISTORS



Semiconductor Materials

MOTOROLA TRAINING INSTITUTE

A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON SA-1
TRANSISTORS

Semiconductor Materials

—one of a series of lessons on two-way FM communications—

MOTOROLA TRAINING INSTITUTE
4501 W. AUGUSTA BLVD., CHICAGO 51, ILLINOIS
APPROVED BY THE STATE OF ILLINOIS
DEPT. OF REGISTRATION AND EDUCATION

PREFACE

This is one lesson of a complete Motorola Home-Study Course which presents to the Service Technician both the principles of operation and the maintenance of two-way FM radio systems. The program covers mobile, portable and base station equipment, including the latest transistorized units.

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SEMICONDUCTOR MATERIALS

LESSON SA-1

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NOTICE

Diagrams and figures referenced in text are "fold-outs" in back of each lesson, for use while studying. The Examinations are also there.

Fire departments were among the first to make use of "Handie Talkie" portable radiophones. Units provide co-ordination of all fire fighting groups at the scene of large fires.

SEMICONDUCTOR MATERIALS

Lesson SA-1

Introduction

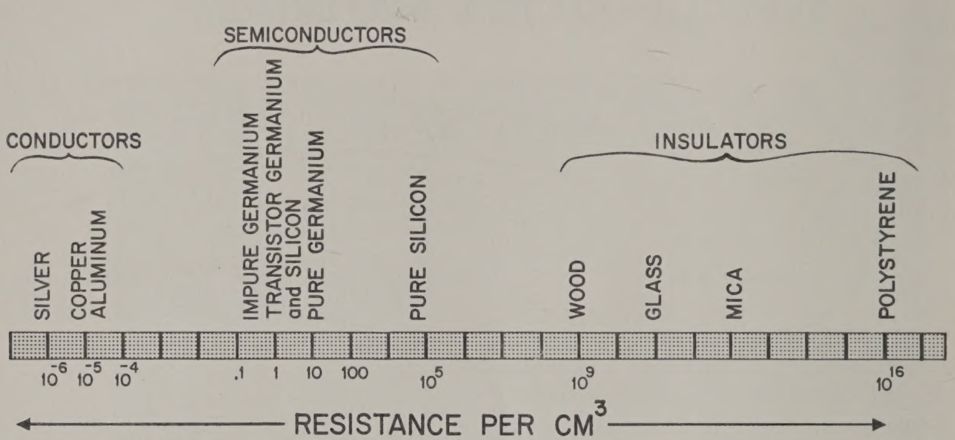
The transistor is a small, lightweight, efficient and highly-reliable device which can perform many of the functions previously assigned to the vacuum tube. The name TRANSISTOR is coined from its operating characteristic--that of a TRANSfer-resISTOR. The material from which the transistor is made is inherently neither a good conductor nor a good insulator--it is semiconductor material. Before proceeding with our study of the transistor, it is well that we first inspect the characteristics of conductors, insulators and semiconductors.

Conduction

Semiconductors do not conduct as well as metals, but they are better conductors than insulators. They are solid materials, and germanium and silicon are the elements most commonly used for transistor construction. (In our discussions of transistors we will speak directly of germanium types, but the same principles apply equally well to silicon devices.) In order to understand the nature of conduction, we must inspect closely the atom and determine why certain materials are better conductors than others.

Figure 1 represents the internal structure and electrical system of a hydrogen atom, the simplest of all atoms. It is generally agreed by physicists that the hydrogen atom has one proton, a positively charged particle, and one electron, which has a negative charge. The atomic number of an element corresponds to the number of protons or electrons in each of its atoms. Thus, hydrogen has an atomic number of one--it is element number one.

In figure 1, the proton (which is always in the nucleus) is shown by a plus sign; the electron is represented by a negative sign. This electron moves around the nucleus in an orbital manner. The term "shell" is commonly used to describe the paths or the areas occupied by electrons. The negative charge of each electron is equal to the positive charge of each nuclear proton, with the result that the atom is in electrical balance--its net electric charge is zero.



The Elements are Often Classified as Conductors, Semi-Conductors and Insulators, According to their Electrical Resistance.

Figure 2 depicts the probable construction of the helium atom. Here there are two protons in the nucleus and two electrons in the first shell--helium is element number two. This atom is also in electrical balance, for there are the same number of electrons as there are protons. In fact, in every atom there is the same number of electrons and protons, so all atoms are normally electrically neutral.

Carbon atoms, illustrated in figure 3, have six protons and six electrons--the atomic number is six. As always the protons are in the center or nucleus, and they are represented by the "plus 6." Again the electrons are orbital about the nucleus, but we find that there are two separate shells. Each shell has a certain number of electrons required in order to fill that shell. For example, the first shell accepts only two electrons. Eight electrons fill the second shell, while the third shell needs eighteen. For the carbon atom, then, two electrons completely fill the first shell and the remaining four electrons are found in a second shell. The electrons in the outer shell of any atom are called "valence" electrons. Thus, the carbon atom has 4 valence electrons.

We are now ready to determine the condition within the atom which allows it to be conductive or nonconductive. Simply, it depends upon the electrons in the outer ring or shell of the atom. In some atoms, these electrons are loosely tied to the atom and may be readily displaced from atom to atom by an electric field. This is the nature of conduction and electricity. Thus, atoms whose outer-shell electrons are easily moved from atom to atom are good conductors.

Conversely, other atoms have outer-shell electrons which are tightly bound, with the result that these electrons are not readily moved from atom to atom. These materials are insulators.

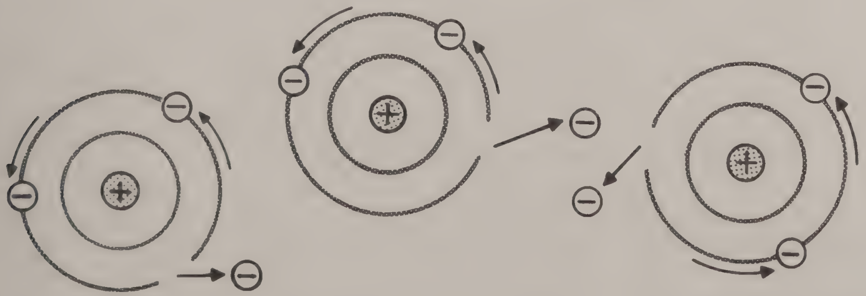
Figure 4 is a representation of an aluminum atom. There are a total of 13 protons and 13 electrons, making aluminum element number thirteen. The first two electron shells are filled with 2 and 8 electrons respectively, and the remaining three electrons are found in the third shell. These outer-shell electrons are readily moved from atom to atom, so the material is a good conductor.

We now have a relatively good picture of the nature of conductivity. If electrons are loosely held and hence capable of being easily moved from atom to atom, the material is a good conductor. When electrons are tightly bound to the atoms, however, the material is an insulator. We are ready to look at the atoms of semiconductors.[1]

Semiconductors

Germanium and silicon, the materials from which most semiconductor devices are made, are tetravalent. This means that there are four (valence) electrons in their outer-most shells. For germanium, these 4 electrons are in the fourth shell; in silicon atoms the 4 electrons are in the third shell. Figure 5 shows the electron arrangement of the silicon atom.

In addition to the fact that there are four electrons in the outer shells and being "in between" the conductors and the insulators, intrinsic (pure) germanium and silicon material is in a crystalline or lattice form which further restricts the movement of the electrons. The effect of this upon the ability of the material to conduct can be seen from figure 6, the representation of the crystalline structure of germanium (or silicon). The small circles represent the nuclei of the atom. The "+4" in each nucleus indicates the 4 protons which counteract (electrically) the 4 valence electrons.



Conduction or Non-Conduction of an Element Depends Primarily Upon the Number of Free or "Valence" Electrons in the Outer Electron Shell.

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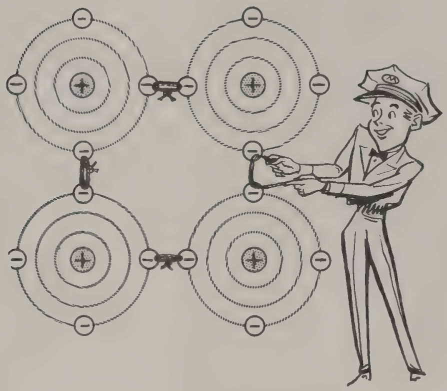
[1] See Basic Theory and Application of Transistors (TM11-690) pages 5-18.



Certain Elements Form Crystalline Structures in Which the Valence Electrons are Held in Place by "Covalent Bonds."

Each of the atoms is equidistant from four other atoms, and is held fast in its position by covalent bonds, a "sharing" of valence electrons by adjacent atoms. These covalent bonds are represented by lines between the atoms. Each electron forms a bond with one of the valence electrons of a neighboring atom so that all of the valence electrons are captured in covalent bonds. These bonds are very stable and strongly bind the electrons to the individual atoms. As a result, there are but few free electrons which may be utilized for current. It seems, then, that this crystal would be a good insulator--and it is, in this intrinsic form. We will now determine what happens when electrons periodically escape from their bonds as shown in figure 7.

Due mainly to thermal agitation, an electron will occasionally gain sufficient energy to escape from its covalent bond. This electron then "wanders" through the material in a haphazard way; there is no scheme to this motion. The path may eventually end near the point where it started, in which case the electron recombines with the atom from which it originated.

When an electron escapes from its covalent bond, it leaves behind it an atom which is no longer electrically neutral, for there are now fewer negative electrons than there are positive protons; that atom becomes a positive ion. See figure 8.

The positive ion has the same amount of electrical charge as the electron, but it is positive in nature. In addition, the ion is fixed in its position in the crystal lattice structure and cannot move about as does the electron. This positive ion represents a "hole" in the structure, a hole that can be satisfied only by the capture of an electron. There is a great attraction for an electron, and any which might wander into the vicinity will be pulled into the hole, once more bringing about a balance.

It is not unusual that a hole will attract an electron from a nearby covalent bond, leaving a similar hole where the electron was pulled from. In this manner the hole may be thought of as moving about in the crystal; the ion doesn't move but, by interchanging electrons, the location of the positive hole changes. This action is often referred to as "hole conduction." This hole movement by an interchange of electrons is a source of electric current.

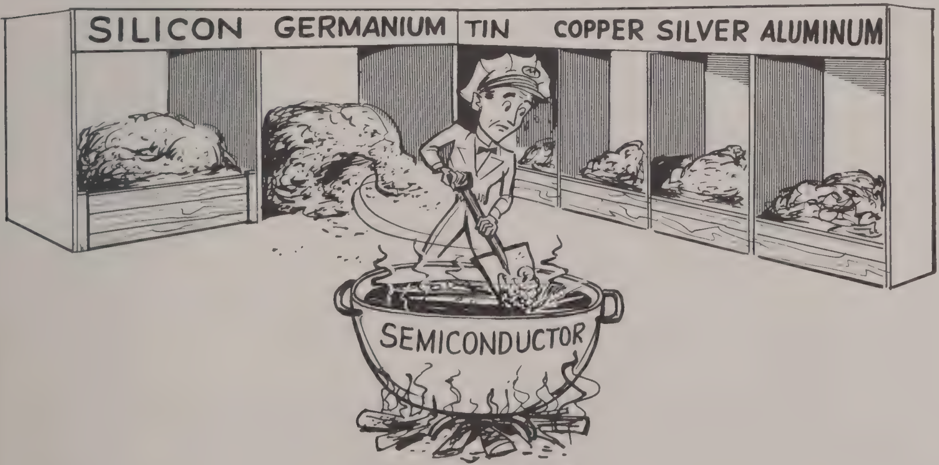
From the above discussion, we see that in the pure semiconductor material (germanium or silicon) the electrons are tightly bound by covalent bonds which prevent any great amount of current through the crystal. Some electrons do break their bonds, however, and they are available for a limited amount of conduction. In the absence of any external force, their motion is haphazard throughout the crystal. They eventually recombine with a positive ion.

An electron breaking from its bond leaves a "hole" which effectively moves about in the material to provide a second source of conduction. As the temperature of the material is increased, the electrons have additional energy; more of them break free from their atoms and are available for conduction. More holes are also present. Higher temperatures thus increase the conductivity of semiconductor materials.[2]

Transistors and other semiconductor devices are not made of the intrinsic material we have been discussing. Instead, a small number of "impurity" atoms are added in order to change the conduction characteristics, as we will now see.

N-Type Semiconductors

A small number of certain impurity atoms substituted for germanium atoms in the otherwise intrinsic germanium crystal greatly changes the conduction ability of the crystal. We will consider first the addition of a pentavalent



Germanium and Silicon are the Materials Most Commonly Used for Making Semiconductors.

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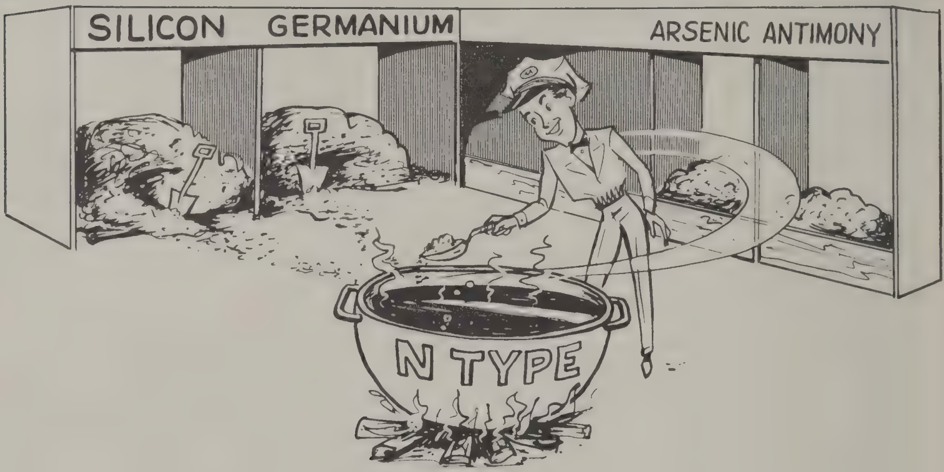
[2] Sec TM11-690, pages 19-21.



"N-Type" Semiconductor Material is Made by Adding a Small Amount of Arsenic or Antimony--Materials Which Have 5 Valence Electrons--to Germanium or Silicon.

material such as arsenic or antimony. (These are called pentavalent because they have five valence electrons in their outer shells.) When a very small number of these atoms are introduced into the germanium crystal (the actual number is usually in the order of 1 in 10 million or less), the crystal takes the form shown in figure 9.

The impurity atom becomes part of the crystal, being located in the position which otherwise would belong to a germanium atom. Four of the electrons in the outer shell of the impurity atom form covalent bonds with electrons of the surrounding germanium atoms, but there is no atom to form a covalent bond with the fifth electron. This leaves the electron free to move about in the crystal. Furthermore, there is no corresponding hole (due to an incomplete covalent bond) created in the crystal by this electron moving about, so that each impurity atom of the crystal provides a free electron.

The conductive properties of the crystal may be controlled by the number of impurity atoms introduced. When the electron leaves the vicinity of the impurity atom, the electrical system of the atom is no longer balanced, for there are more protons than electrons. The atom is a fixed positive ion, for it is not free to move about in the crystal as is the released electron.

The number of free electrons in the crystal doped with pentavalent material is much greater than for the intrinsic material. Because pentavalent doping produces free electrons within the crystal structure, the material has a negative characteristic--the current established in the crystal will be due to the motion of these electrons. For this reason, it is common to refer to this material as an N-type semiconductor. Because they "donate" electrons to the crystal structure, pentavalent atoms are often called "donors."

P-Type Semiconductors

We will consider now the effect on introducing into the germanium crystal a small number of trivalent atoms, such as indium, aluminum or gallium. These materials are called trivalent because their atoms have three valence electrons in their outer shell. Again the number of impurity atoms within the germanium crystal is very small. The crystal formation shown in figure 10 results.

Each impurity atom (we will assume indium for convenience) is surrounded by four germanium atoms. Three electrons are available in the outer shell (of the indium atom) to enter into valence bonds with neighboring atoms, but there is no electron to complete the fourth covalent bond. Because there is no electron to complete the crystal covalent bond structure, we have a "hole."

This hole exhibits a great attraction for an electron, so in effect we have a positive hole--there is need for another electron. In fact, it is not uncommon for an electron associated with a nearby atom to be pulled into this hole, leaving a hole at the atom from which the electron was removed. Thus, the hole effectively moves about in the crystal. One such hole is created for each impurity atom added to the crystal.

Without an applied external field, the movement of the holes within the crystal is haphazard. With an applied field, however, the drift of these holes is consistently toward the negative point, and current (by hole conduction) is established. These holes are then considered to be the carriers, the means of establishing current in this P-type semiconductor. The indium atoms are commonly referred to as "acceptors," for they capture any electron in the vicinity.

By pulling an electron into the crystal structure, an acceptor atom becomes negatively charged, for there are now more electrons associated with the atom than there are protons in the nucleus. Such negative ions are fixed by their covalent bonds and cannot move through the crystal structure.[3]

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3. See TM11-690, pages 21-30.

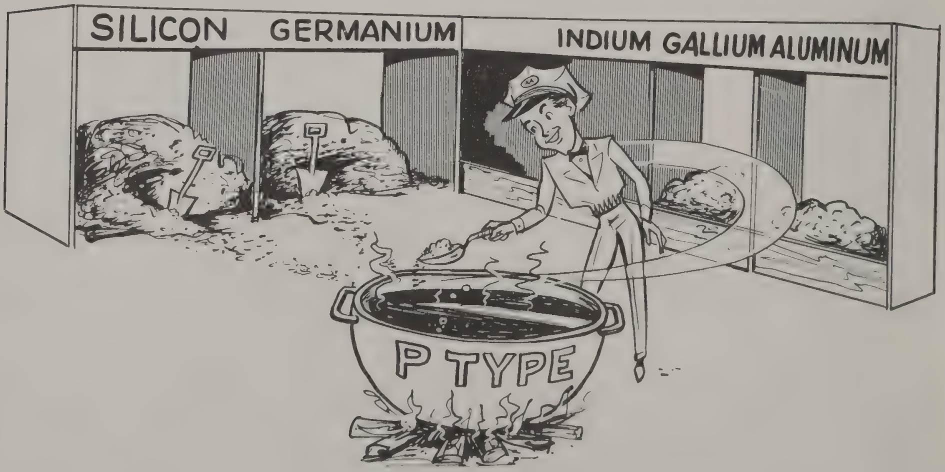
Majority and Minority Carriers

Regardless of whether a semiconductor material is of the N or P type, both electrons and holes are available to be used as carriers. This is caused by the electrons breaking away from their covalent bonds. In most cases, these electrons and holes recombine so that the main conduction is due to electrons or holes created by the impurity atoms. For N-type material, then, we consider the electrons as being the majority carrier or means of conduction, and for P-type material the holes are considered as the majority carriers. In N-type material there are always a few holes, so they are the minority carriers, and electrons are considered as minority carriers of P-type materi-

Conduction Within N-Type Materials

Before leaving the subject of conduction, let us see the effects of applying voltages to both N and P semiconductors. We will start with the N type--see figure 11.

In figure 11A, the voltage source makes the right side of the material negative and the left side positive. The free electrons (the majority carriers in N material) are attracted to the left or positive side. There will be current in the complete circuit as shown; this current is measured by the meter. The amount of current is determined by Ohm's Law (I = E ÷ R), in which case the R is the effective resistance of the semiconductor



"P-Type" Semiconductor Material is Made by Adding Small Amounts of Indium, Gallium or Aluminum--Materials Which Have But 3 Valence Electrons--To Germanium or Silicon.

Electrons leaving the crystal at the left side are replaced by electrons entering the crystal at the right. While this action constitutes the majority of the current in the circuit, there is a small amount of current due to minority carriers (holes) moving in the opposite direction. Hole current is always considered to move in the circuit from the positive side of the material to the negative side (the "conventional" direction of current).

In figure 11B we find the same piece of N material but with the battery polarity reversed--the positive side of the battery is now connected to the right side. The action is the same as before, but the electrons are attracted to the right side of the material and the holes to the left. The ammeter must now be connected with the polarity shown. From this action we see that the N-type semiconductor material is capable of conducting current equally well in either direction. As we shall see in the next lesson, conduction in one direction only (rectification) is realized only when a junction is made of P and N materials.

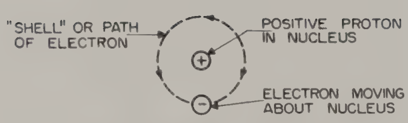
Conduction Within P-Type Material

Figure 12 shows the conduction within P material when an external voltage is applied. At 12A the battery makes the left side of the crystal positive with respect to the right side. In the external circuit between the battery and the semiconductor, we consider the current as corresponding to the electron flow, from the negative side of battery to the semiconductor and from the semiconductor back to the positive side of the battery.

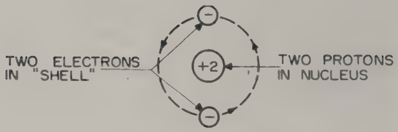
Within the semiconductor, however, the current is due mainly to a movement of "holes," which are the majority carrier. Holes move internally from the positive side to the negative side, from right to left. If we wish to correlate this action with the movement of electrons, we can remember that the movement of holes in the material is due to electrons being interchanged from one atom to the next, in which case the electron drift is in the direction opposite to the hole movement. The ammeter in figure 12A records the circuit current, and again the amount is determined by the applied voltage and the resistance of the material.

Figure 12B uses the same P material, but the applied voltage has reverse polarity. The holes inside the P material are attracted to the left side, so that the circuit current is now reversed. Reversing the battery polarity doesn't change the amount of current in the circuit, it merely changes the direction.

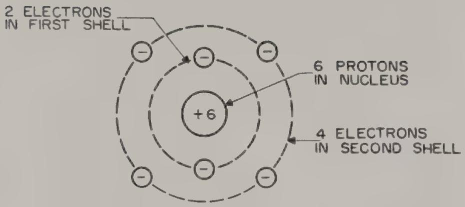
We have seen the nature of the conduction within N- and P-type semiconductors. In the next discussion we will continue with the study of semiconductors made into P-N junctions (diodes).


"SHELL" OR PATH OF ELECTRON
POSITIVE PROTON IN NUCLEUS
+
−
ELECTRON MOVING ABOUT NUCLEUS

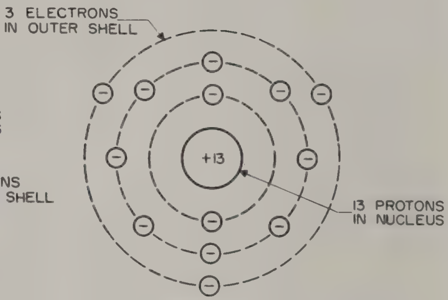
HYDROGEN ATOM
FIGURE 1



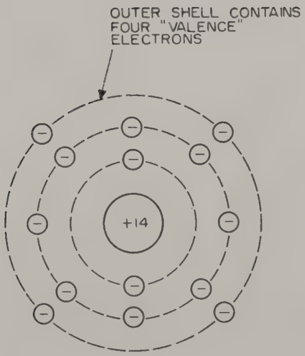
HELIUM ATOM
FIGURE 2



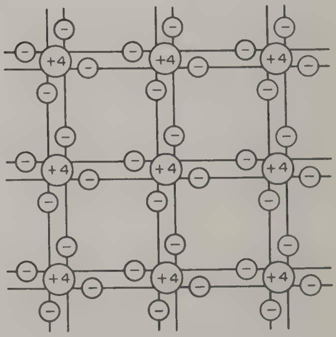
CARBON ATOM
FIGURE 3



ALUMINUM ATOM
FIGURE 4



SILICON ATOM
FIGURE 5



GERMANIUM CRYSTAL DIAGRAMMETICAL
SKETCH. FIGURE 6

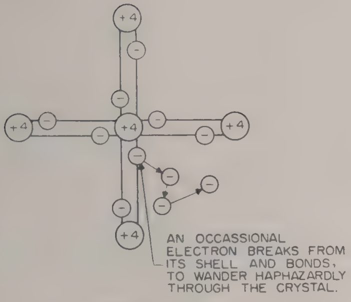

+4
+4
+4
+4
+4
AN OCCASSIONAL ELECTRON BREAKS FROM ITS SHELL AND BONDS, TO WANDER HAPHAZARDLY THROUGH THE CRYSTAL.

FIGURE 7

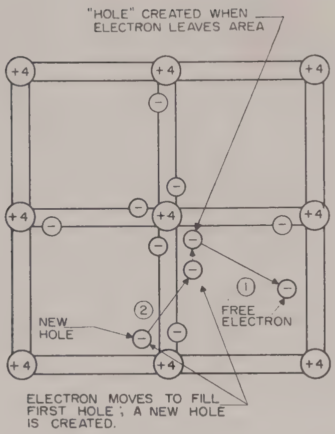
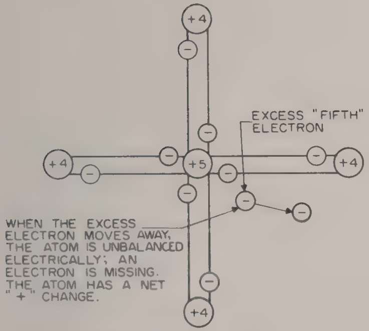
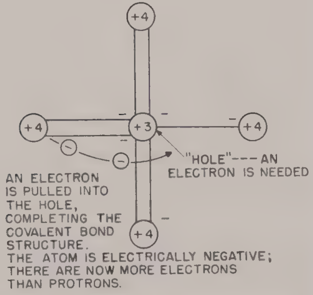

"HOLE" CREATED WHEN ELECTRON LEAVES AREA
+4
①
②
FREE ELECTRON
NEW HOLE
ELECTRON MOVES TO FILL FIRST HOLE ; A NEW HOLE IS CREATED.

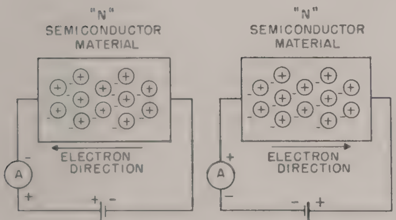
FIGURE 8


+4
+5
EXCESS "FIFTH" ELECTRON
WHEN THE EXCESS ELECTRON MOVES AWAY, THE ATOM IS UNBALANCED ELECTRICALLY; AN ELECTRON IS MISSING. THE ATOM HAS A NET " + " CHANGE.

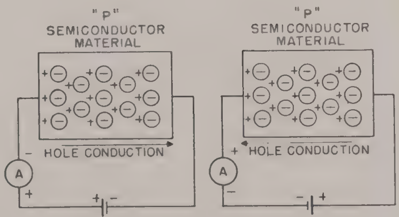
"N" DONOR ATOM IN GERMANIUM CRYSTAL
FIGURE 9


+4
+3
"HOLE"---AN ELECTRON IS NEEDED
AN ELECTRON IS PULLED INTO THE HOLE, COMPLETING THE COVALENT BOND STRUCTURE.
THE ATOM IS ELECTRICALLY NEGATIVE; THERE ARE NOW MORE ELECTRONS THAN PROTRONS.

"P" ACCEPTOR ATOM IN GERMANIUM CRYSTAL
FIGURE 10



11A 11B
CURRENT IN N-TYPE SEMICONDUCTOR
FIGURE 11



12A 12B
CURRENT IN P-TYPE SEMICONDUCTOR
FIGURE 12

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Please PRINT or use STAMP

Name ______________________________ **Student No.** ______

Street __________________ **Zone** ____ **Date** ______

City _______________ **State** ________ **Grade** ______

EXAMINATION, LESSON SA-1

1. From what kind of material are transistors made?
   A. Insulator______ [✓ B. Semiconductor] ______ C. Conductor______
2. The element from which transistors are most commonly made is:
   A. Silver______ B. Copper ______ C. Helium______ [✓ D. Germanium] ______
3. Which of the following statements are true about the electrons in the outer shell of an atom? (Select more than one answer.)
   [✓ A.] They are called valence electrons.
   [✓ B.] They determine the conductivity of the material. ______.
   C. They are always held fast in covalent bonds. ______.
   [✓ D.] They have a negative electrical charge. ______.
4. The valence electrons of a particular substance cannot be easily moved from atom to atom by an electric field. This material is [✓ (an insulator)] (a conductor). Another substance has electrons which are easily moved by an electric field. This material is (an insulator) [✓ (a conductor)].
5. Germanium and silicon atoms each have 5 electrons in their outer shell. TRUE______ FALSE______. Furthermore, these electrons are held in place by covalent bonds formed between them and the protons of neighboring atoms. TRUE______ FALSE______. When electrons are held in covalent bonds, the material is usually in a crystalline form. TRUE______ FALSE______.
6. An electron breaks away from its covalent bond in a crystalline structure. The atom now has (a surplus of electrons) (an electron deficiency) and is (positively) (negatively) charged. The atom is now (a proton) (an ion) and will (attract) (repel) any free electrons in the area.
7. A germanium crystal has been "doped" with a small amount of arsenic, a pentavalent material having 5 valence electrons in its outer shell. The crystal now has a (surplus) (deficiency) of electrons to form covalent bonds and as a result the crystal exhibits a (negative) (positive) characteristic due to its (free electrons) (holes).
8. "Acceptor" impurities produce (P-type) (N-type) semiconductor material. The impurity atoms have (3) (4) (5) valence electrons. (Indium) (Arsenic) (Silicon) is a typical acceptor-type impurity material.
9. In P-type semiconductor material, conduction is due mainly to the movement of (holes) (electrons). In N-type semiconductors, holes are the (majority) (minority) carriers.
10. In figure A indicate:
    A. The direction of current through the semiconductor material which is due to the movement of "holes."
    B. The polarity of the ammeter terminals.

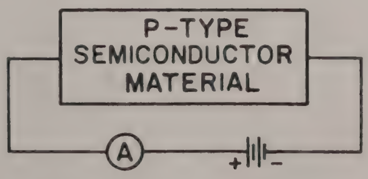

FIGURE A

national
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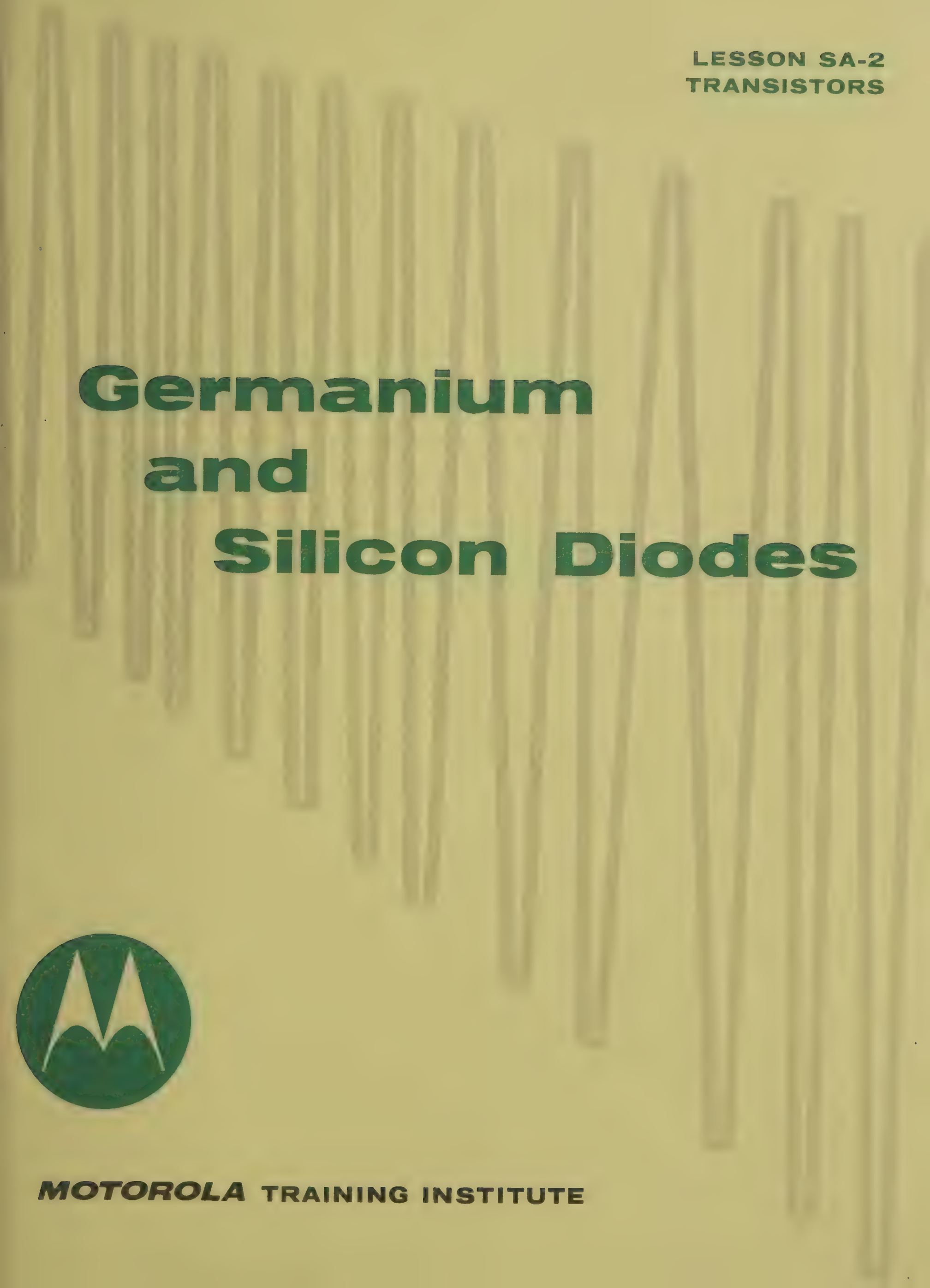
service

A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON SA-2
TRANSISTORS



Germanium and Silicon Diodes

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LESSON SA-2
TRANSISTORS

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SILICON AND GERMANIUM DIODES

LESSON SA-2

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NOTICE

Diagrams and figures referenced in text are "fold-outs" in back of each lesson, for use while studying. The Examinations are also there.

Construction foremen can communicate throughout project area when equipped with portable radiophones. Through extensive use of transistors such instruments are lightweight and low in power drain.

SEMICONDUCTOR DIODES

Lesson SA-2

Introduction

In the preceding lesson, we studied the nature of semiconductor materials which have been "doped" by P and N impurity atoms. We found that in the N-type semiconductor the impurity atoms provide a supply of free electrons, which become the current carriers; in P-type semiconductors, the added impurity atoms create a deficiency of electrons, leaving "holes" in the structure, which become the carriers.

In this lesson we shall study the nature and operation of semiconductor diodes. Two such diodes are possible, the junction diode and the point-contact diode. We will start with the junction diode.

The Junction Diode

When a junction is made of P-type and N-type semiconductor materials, we have a device possessing rectifying characteristics similar to those found in vacuum tube diodes. This device is called a "junction" diode. For the main part these diodes are used where high current levels are involved, as in power supplies.

As a start, we will assume that a block of P-type material is brought into contact with a block of N-type material. See figure 1. (In practice, junctions are not formed in this manner, but it well illustrates the action which takes place.) When the two materials are first brought into contact an interaction occurs between the carriers. Before we can understand how this junction rectifies, it is necessary to determine the exact nature of this initial action and the condition of the carriers after the junction has been formed. See figure 2.

At the left in figure 2 we find the P material with its "holes." The N material with its excess electrons is at the right. When the junction is formed, the holes and electrons at the surfaces of the materials combine. That is, electrons move across the junction and into the P material, and the holes cross the junction to reach the N material. When this occurs, fixed ions are "uncovered" on the right side of the junction, for there are now too few electrons to produce a balanced electrical condition. On the left side of the junction, the negative fixed ions of the crystal structure are evidenced. These ions are fixed within the lat-

Adjoining Layers of P and N Semiconductor Materials Produce a P-N Junction: this is a Semiconductor Diode.

tice structure of the crystalline materials; they are unable to move about.

The fixed negative ions at the left of the junction repel the free electrons at the right. At the same time, the positive ions at the right side have a repelling effect upon the positive carriers in the P material at the left.

In addition, the fixed positive ions on one side of the junction and the fixed negative ions on the other side of the junction produce an electric field across the junction, the same as a charged capacitor sets up an electric field in its dielectric material. This electric field, called the "barrier field," means that a voltage exists across the junction. This field discourages any further exchange of carriers across the junction and the area occupied by the uncovered ions is known as the "depletion area."

Before any further action can take place, it will be necessary either for the electrons on the right to have sufficient energy or force to overcome the field set up in the depletion area, or for the holes on the left to be "helped" across the junction by some external energy source. This can be accomplished by applying a voltage to the junction, and this voltage must have the proper polarity, as illustrated in figures 3 and 4.[1]

Reverse Bias

In figure 3, the positive side of the battery is connected to the negative or N material, and the negative side to the positive or P material. As soon as the voltage is applied, we again have an initial action taking place. Electrons within the N material are pulled away from the junction, toward the positive terminal of the battery. This uncovers more fixed positive ions near the junction.

Holes within the positive P material are attracted to the negative battery terminal, uncovering additional fixed negative ions at the left side of the junction. Due to the greater number of fixed ions at each side of the junction, we have a stronger barrier field existing at the junction, and the depletion layer is also wider. It is now more difficult for carriers to cross the junction.

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[1] See Basic Theory and Application of Transistors (TM11-690), pages 30-33.

Thus, when a voltage of the polarity shown in figure 3 is applied to a P-N junction, it is more difficult to establish current across the junction than it is without the applied voltage. This voltage is commonly referred to as a "reverse bias." The polarity is easy to remember when we recall that the positive side of the battery goes to the N material and the negative side of the battery to the P material--the polarities are "reversed."

While there is usually some current across the junction even when it is reverse biased, this current is very small and may be disregarded for our present discussion. (As we shall soon see, too much reverse bias can break down the junction structure and cause a high reverse current.)[2]

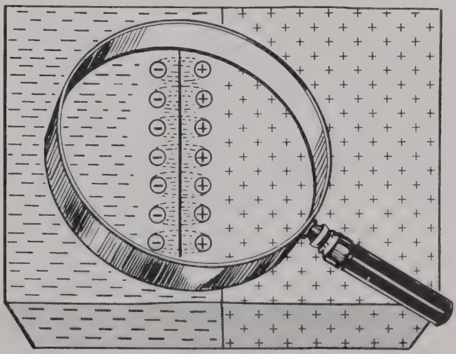
Forward Bias

Forward bias has the exact opposite effect upon the current across the P-N semiconductor junction. Instead of opposing any movement of carriers across the junction, forward bias encourages junction current. Figure 4 shows forward bias.

The components of figure 4 are the same as those of figure 3. The only difference is that the battery connections have been reversed, and the ammeter will show considerable current. In order to provide forward bias, the positive side of the battery goes to the P material and the negative side of the battery to the N material. Let's see what is happening at the junction.

The battery tends to produce a field at the junction which opposes the barrier field created by the fixed ions. The external voltage actually only reduces the internal field so that the electrons on the right side of the junction readily move across the junction into the P material and continue on to the positive side of the battery. The holes at the left side also have sufficient energy to cross the junction.

The depletion layer is greatly reduced and represents but a minimum amount of resistance. The current is thus high, being limited by the number of carriers in the N and P material, the size of the junction, and the applied voltage.[3]



At the P-N Junction, the Fixed Charges Produce a "Barrier Field" Within the Depleted Area.

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[2] See TM11-690, pages 33-34.

[3] See TM11-690, pages 34-35.

Diode Current Characteristics

We have already seen that forward bias produces current across the semiconductor diode, but reverse bias produces little or no current. The curve in figure 5 illustrates the magnitudes of these currents in relationship to the bias voltage.

With forward bias, the current increases according to the amount of applied voltage. The only point that is appreciably curved is at the very low values of forward bias. The amount of current produced is determined to a very large degree by the size of the junction and the intensity of the impurity atoms in the N and P sections. Larger junctions and a higher percentage of impurity atoms increase the current capability of the diode.

While there is little or no current through the diode with reverse bias, it is well to see the characteristics of this current. In figure 5 we see that a small value of current is present with reverse bias, and this current does not change as the bias is increased. That is, there is no noticeable increase until the point of junction "breakdown" occurs. The reverse current in the junction then suddenly increases to a high value. This is due to the breakdown of the covalent bonds within the crystal structure at the junction, releasing a large number of free electrons and holes for current conduction.

As soon as the excessive reverse bias is removed, the junction returns to its original condition (provided that the junction has not been damaged by heat). If the crystal structure has been damaged, the unit will no longer be efficient as a rectifier.[4]

Symbols

The accepted symbols for semiconductor diodes are shown in figure 6. The P material is represented by the arrow and the N material by the line. As shown, the arrow may or may not touch the N line, but this has no significance as far as the symbol is concerned.

The arrow indicates the conventional direction of current, from positive to negative. Electron movement through the diode is in the opposite direction. Figure 7 points out these two "directions of current" in a circuit. It matters not which direction is assumed, for the circuit currents and voltage drops are unchanged.

For example, look at the resistor in figure 7. Following the conventional positive to negative direction, the current enters the resistor from the bottom and leaves at the top. Using this direction of current the bottom is positive and the top is negative. If electron flow is assumed, the current is from the top down through the resistor, but here the side the electrons enter is negative so again the top is negative and the bottom positive. Thus, the difference is only in the viewpoint taken and does not change what takes place in the circuit.[5]

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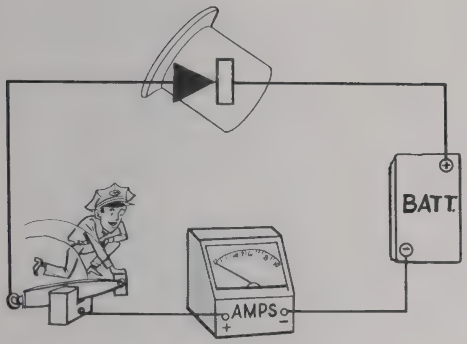
[4] See TM11-690, page 35.

[5] See TM11-690, page 42.



Reverse Bias Applied to the Semiconductor Diode Does Not Produce Current at the Junction.

Half-Wave Rectifier

One common use for the semiconductor diode is as a half-wave rectifier, shown in figure 8. Here we find an AC source, a rectifier, and a load. The arrows show the direction of conventional current, from positive to negative. During the positive alternation of applied current, the upper terminal of the generator is positive with respect to the lower terminal; the voltage applied to the diode is a forward bias, with the result that the diode is conductive.

The amount of current is determined mainly by the value of the load resistance and the applied voltage. The resistance of the diode is relatively small compared to that of the load, so the internal voltage drop of the diode is very small and for all practical purposes the full source voltage appears across the load.

During the next alternation, the upper terminal of the generator is negative with respect to the lower terminal; this voltage applied to the diode is a reverse bias and there is no circuit current. Thus, there is no voltage across the load, and all of the voltage appears across the diode.

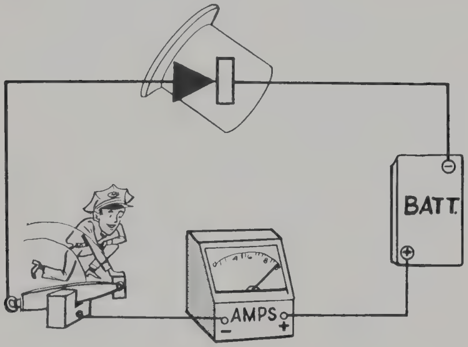
The action taking place in figure 8 is no different from that in a vacuum tube diode rectifier circuit. The internal voltage drop of the semiconductor diode is usually less than that of the vacuum tube, however, with the result that the output voltage (load voltage) is greater. Other advantages are found in the efficiency, ruggedness, reliability and size of the semiconductor diode. Silicon diodes are perhaps the most popular type of semiconductor rectifier used today.

Full-Wave Rectifier

A full-wave rectifier is normally preferred to a half-wave rectifier. Figure 9 is a typical example. A transformer secondary winding is center-tapped and diodes connected in series with the load rectify the AC voltage to DC.

At A, we see the action when the applied AC makes the upper terminal of the secondary positive with respect to the bottom. Considering each half of the secondary, the upper terminal is positive (with respect to the center tap) while the bottom terminal is negative.

The upper diode is now forward biased and conducts through the load resistor, producing a voltage with the right side being positive. During this time the lower diode is reverse biased and nonconductive. Thus, during the first alternation the upper diode rectifies the voltage of the upper half of the secondary and this voltage appears across the load.



Forward Bias at the Semiconductor Diode Causes Current Through the Junction.

At B, we see the action during the second half-cycle. The lower secondary terminal is positive and the upper terminal is negative. The lower diode is now forward biased and conducts through the load, once more making the right terminal positive. During this second alternation, the upper diode is reverse biased and nonconductive.

From the above, we see that each alternation of the applied voltage causes one of the diodes to be conductive. The waveforms show that each alternation appears across the load.

Full-Wave Bridge Rectifier

Another semiconductor rectifier circuit commonly found in two-way communications equipment is shown in figure 10. Here the transformer secondary has no center tap. The rectifiers operate from the full secondary voltage and the full secondary voltage appears across the output.

During the half-cycle when the applied voltage is positive at the top of the winding, rectifiers CR1 and CR4 are forward biased and allow current as shown by the solid arrows. The current through the load makes the right side positive. During this time, rectifiers CR2 and CR3 are reverse biased and nonconductive.

During the second half-cycle, when the bottom of the transformer is positive, rectifiers CR2 and CR3 are forward biased and become conductive--the direction is shown by the broken arrows. The current is through the load in the same direction as before, making the right side positive.

Types of Junction Diodes

Two main types of construction are used for junction diodes, the grown junction and the fused junction. See figure 11.

The grown junction is represented at figure 11A, and here we see what appears to be a block of N material and a block of P material placed together. This is not the actual method of manufacture, however. Instead, we start with one type of material, usually "N." When the crystal is partly grown, the characteristic is changed by adding some P impurities to the mixture. The rest of the crystal, then, is made of P-type material. Large contacts are made to each end of the crystal to complete the diode.

The fused junction diode is made in a different manner. A small bead of P impurity material (usually indium) is placed on an N-type wafer. See 11B. This assembly is placed in an oven for a specific period of time and heated to a temperature at which the P atoms fuse into the N wafer, producing P-type germanium at the surface of the wafer. This produces a P-N junction between the indium and the N wafer.

Point-Contact Diodes

A second type of semiconductor diode is called "point-contact." These diodes are restricted to low current applications, but their characteristics are such that they become very useful at higher frequencies, particularly the very high frequencies where vacuum diodes are no longer practical.

Figure 12 illustrates the internal construction of a point-contact diode. The active elements are the crystal wafer and the "cat whisker." The metal base makes good contact with the crystal and the cat whisker has a direct connection to the second external lead. The parts are enclosed in insulating material to protect them from moisture and the assembly is then encapsulated.

The symbol for the point-contact diode is the same as for the junction diode (figure 6). The long line or bar indicates the crystal element (which is the cathode) and the arrow is the cat whisker (which is the anode). If we analyze current through this unit, the conventional direction will be represented by the arrow, from anode to the cathode. Electron flow is opposite to the direction of the arrow, from cathode to anode.

The point-contact diode is usually made from a thin wafer of N material and a beryllium-bronze wire. In the manufacturing process, current is pulsed through the contact and supposedly produces a P region in the wafer, directly under the metal point (the exact action is not completely known). An extremely small P-N junction is thus formed. Due to the very small dimensions of this junction, the unit has very little effective capacitance and provides efficient operation at high frequencies. In addition, the junction transit time is short, for improved high-frequency operation.

Point-contact diodes are made of both germanium and silicon. Originally the silicon type were more satisfactory for high-frequency application, but recent improvements have made the germanium diodes useful in applications such as high-frequency mixers or detectors. The point-contact diode is used extensively where low forward resistance and a small reverse current are desirable. Typical applications are as second detectors, discriminators, limiters, and clippers. Figure 13 shows two typical circuits for point-contact diodes.[6]

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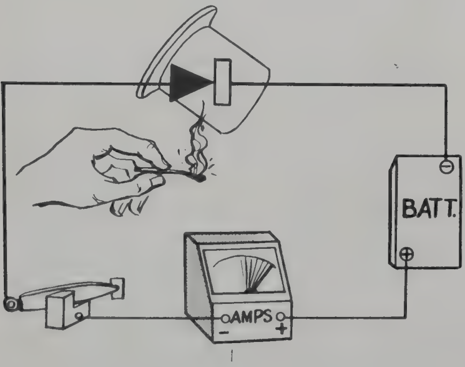
[6] See TM11-690, page 5, also see "Understanding Semiconductor Diodes," reference S-2.

Silicon Diode Applications

In addition to their use as power rectifiers, silicon diodes provide certain services not possible with vacuum tubes or germanium devices. These are due to the inherent forward current and reverse current properties of silicon junction diodes. In the forward direction, the current does not increase beyond a fraction of a microampere until the voltage reaches as much as .3 or .4 volt. In the reverse direction, the current is again very low until a certain breakdown voltage is reached, at which time the reverse current increases rapidly to a maximum value.

Both of these pecularities are also evidenced in the germanium diode, but the action is more gradual with the amount of applied voltage. In addition, the stability and reliability do not approach that achieved with the silicon diode.



An Increase in Diode Temperature Causes an Increase in Diode Current.

We shall now look at these two characteristics more closely and see how they become useful. Let us start with forward current.

In figure 14, we see a typical forward-current curve for a silicon diode. As the forward voltage increases from zero, the current remains at a fraction of a microampere until the voltage reaches 0.3 volt. With greater voltages, the current rises to a relatively high value, the amount depending upon the voltage.

We are not interested in the value of current which is produced by these higher voltages, but in the fact that the current is very low up to the point of about 0.3 volt and then suddenly rises to a high value with greater voltages.

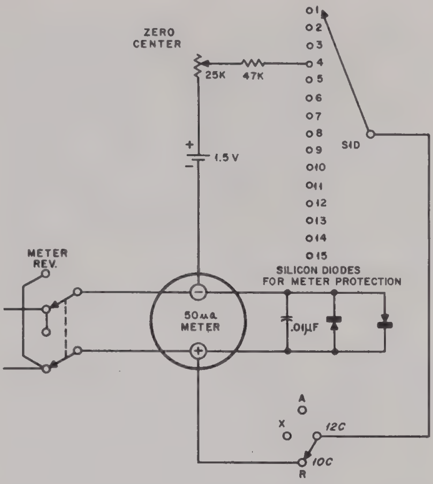
Figure 15 is a practical circuit for protecting a sensitive meter from excessive overloads by connecting a silicon junction diode in parallel with the meter movement. (Assume that this diode has a forward current characteristic similar to that shown in figure 14.)

The meter sensitivity is 50 microamperes, and the internal resistance is 2000 ohms. Applying Ohm's Law ($E = I \times R$), the voltage across the meter at full-scale deflection is 0.1 volt. This means that when the meter is at full-scale deflection, the voltage across the diode is also 0.1 volt.

Looking at the curve of figure 14 for this diode. With 0.1 volt applied, the current will be a fraction of 1 microampere and the meter sensitivity will be virtually unaffected by the current through the diode. If the diode were to conduct any appreciable amount of current, the meter reading would not be accurate, for much of the current would be bypassed around the meter.

Meter protection is provided when we consider an overload of the meter, in this case a three-to-one overload. When the current is 150 ua, the voltage across the meter is 0.3 volt, and the diode is at the point where it is about to conduct. Any further increase of current will place the diode at a point of high conduction; any further increase of current will thus be through the diode rather than through the meter. Once the meter current has reached a certain maximum amount, additional current will be through the diode with very little additional increase through the meter.

Meter movements are built to withstand a certain amount of overload current, and a diode is selected which will conduct or bypass the current around the meter before reaching the value of current which will damage the meter.



Here We See the Protective Diode Meter Circuit of the Motorola Test Set.

Improved protection of the meter (the maximum allowed meter current is closer to its rating) is possible by adding a resistor in series with the meter movement as shown in figure 16. Here the added resistor is 2000 ohms, doubling the resistance of the meter branch. Now 50 ua through the meter will cause a total drop of 0.2 volt across the diode. For an overload of 2 to 1, the voltage across the diode will be 0.4 volt and the diode will be in full conduction. For this arrangement the meter current will never be greater than 100 ua, which is only a 2-to-1 overload.

Higher values of resistance will bring the diode closer to conduction for full meter deflection and given even closer protection, but the diode current under adverse conditions is likely to shunt appreciable current around the meter before full-scale current is realized. Among the most adverse of these conditions are high temperatures.

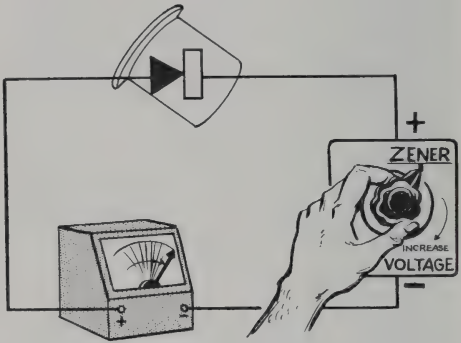
Where it is desirable to protect the meter from overload current in both directions, it is practical to connect two diodes in parallel with the meter, one in each direction (figure 17). When the circuit current makes the upper terminal positive with respect to the lower terminal, diode D1 will protect the meter (as already explained for figures 15 and 16).

Diode D2 affords protection from excessive currents through the meter in the opposite direction. The leakage current through the reverse connected diode is negligible. The arrangement of figure 17 is the same as that of the Motorola Model TU 546 test set, discussed in Lesson MA-3 (figure 9).

Zener Silicon Diodes

If we refer back to figure 5, we recall that reverse bias on a diode produces little current--so very little as to be forgotten in most applications. In addition, we saw that if the reverse bias is increased to a certain point, the unit suddenly becomes very conductive and a large current is established. This current, we found was due to a breaking down of the crystal structure within the boundaries of the junction.

This is commonly called the Zener effect: diodes designed to make use of this action are called Zener diodes. At present, silicon diodes are used almost exclusively for this purpose. (Zener is pronounced ZEE'ner.)



When the Reverse Voltage at the Diode is Increased to the "Zener" Voltage, a Large Current Suddenly Occurs.

In general, we can think of a Zener diode as having the same purpose as the gas filled tube--that of maintaining a constant voltage across its terminals. While the method by which the diode achieves this goal is somewhat different from that of the gas-filled regulator tube, the overall action is the same. Look at figure 18. Here a Zener diode is used as a DC voltage regulator.

In figure 18, the diode is placed in parallel with the circuit to be regulated, but in reversed polarity. In series with the diode (and load) we find a resistor. The unregulated supply must have sufficient voltage to be equal to the desired value of regulated voltage and the drop across the resistor; in most applications the unregulated supply is several times larger than the load voltage. The supply voltage causes the Zener diode to be conductive, under which condition it maintains a constant voltage equal to its breakdown value.

Zener diodes are available with breakdown ratings ranging from a few volts to as much as 300 volts. Where higher voltages are required, several units may be placed in series, in which case the breakdown value will be the sum of the separate ratings. (For this application it is advisable to use units of similar ratings.) While the Zener diode serves the same purpose as voltage regulator types of tubes, they have the advantage that smaller voltage ratings are possible. "VR" tubes are practical only at values between 75 and 150 volts.

The Zener characteristic curve of the silicon diode shows that additional current through the diode does not appreciably change the voltage across the diode. Besides serving as a convenient means of providing voltage regulation, the constant voltage across the diode becomes a source of reference voltage. Regardless of changes of input voltage, the voltage across the diode remains relatively constant and serves as a source of known, fixed voltage. The circuit for this service is similar to that of figure 18 and is given in figure 19.

The voltage across the diode becomes a "reference" and remains steady over a relatively wide range of conditions. A known voltage is convenient for calibration of instruments, etc. The variable resistor allows adjustment for the correct current through the diode, assuring stable operation. The current must be limited to a safe value--below the dissipation rating of the diode.

The Zener diode may also be used as a means of providing an AC reference voltage of constant amplitude. Figure 20 gives a simple arrangement. The circuit is basically that of a limiter. The diodes are connected back-to-back so that one diode limits in one direction and the second diode in the opposite direction.

Operated from an AC source, during the first half cycle diode D1 conducts, the voltage rising until the Zener voltage rating of Diode D2 is reached. Both diodes are now conductive and the voltage cannot increase further. When the next alternation is applied, diode D2 is conductive but diode D1 does not conduct until its breakdown voltage is reached.

If the diodes have the same value of breakdown voltage, the positive and negative portions of the output waveform will have the same amplitude; the total or peak-to-peak voltage will be twice the breakdown value of one unit. Where the applied voltage is considerably greater than the breakdown voltage, the output waveform will be a square wave. Input voltages not reaching the Zener operation of the diodes will not produce full output voltage.

Identifying Diode Elements

One problem often encountered in service work is the identification of the anode and cathode terminals of semiconductor diodes from their markings or construction. While absolute identification is not always possible, due to inconsistencies from one unit to the next, the following generalities should help identify most of them.

Let us compare first the symbols for the vacuum tube diode and the semiconductor diode, shown as A and B of figure 21. The arrow of the semiconductor corresponds to the plate of the tube and the bar corresponds to the tube cathode. Thus, on some diodes we can logically expect to find a K, indicating the cathode. See E in figure.

Other diodes have a "+" and this also identifies the cathode terminal. This marking is justified when we remember that the cathode terminal of a diode used as a rectifier connects to the positive side of the resulting DC load voltage. (See C in the figure.)

Some diodes have neither "K" nor "+" markings, but there may be a dot or one or more color bands near one end. (See D, F. and I of figure 21.) Again this end is the cathode. Often a diode with color bands will also have a letter at the anode end, which identifies the manufacturer.

A final group of semiconductor diodes have no marking of any kind to identify the terminals, but they are built with an irregular shape at one end in order to indicate the cathode. Examples are found at G and H of figure 21.

We can summarize this discussion by saying that any identification on the semiconductor diode, be it "k," "+," a dot, color bands or an irregular shape, usually indicates the cathode.

STUDENT NOTES

STUDENT NOTES

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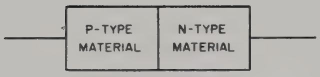
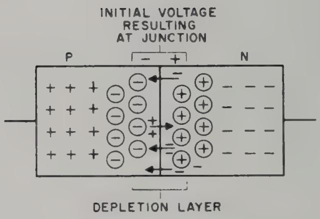


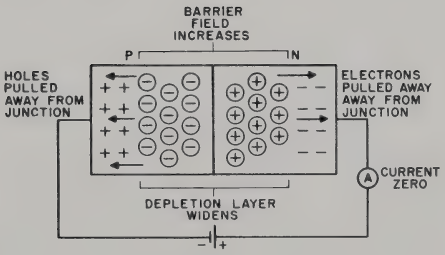
JUNCTION TRANSISTOR

FIGURE 1



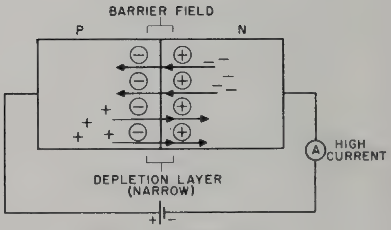
BARRIER FIELD OF JUNCTION DIODE

FIGURE 2


BARRIER FIELD INCREASES
P
N
HOLES PULLED AWAY FROM JUNCTION
ELECTRONS PULLED AWAY AWAY FROM JUNCTION
A
CURRENT ZERO
DEPLETION LAYER WIDENS

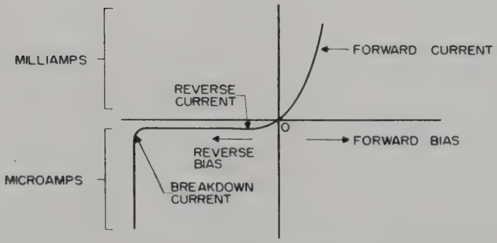
REVERSE JUNCTION BIAS

FIGURE 3



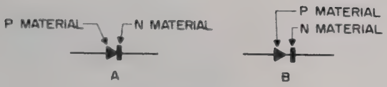
FORWARD JUNCTION BIAS

FIGURE 4



CURRENT CHARACTERISTICS OF SEMICONDUCTOR DIODES

FIGURE 5



SYMBOLS FOR SEMICONDUCTOR DIODES

FIGURE 6

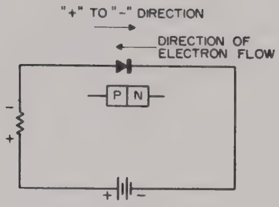
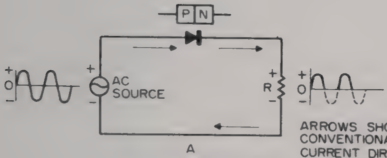
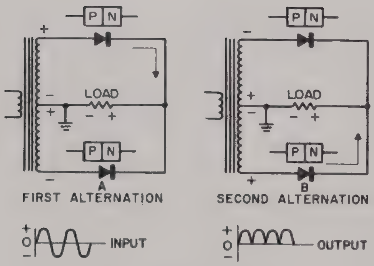


FIGURE 7



ARROWS SHOW CONVENTIONAL CURRENT DIRECTION

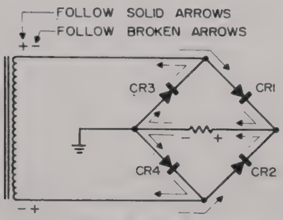
HALF-WAVE RECTIFIER
FIGURE 8



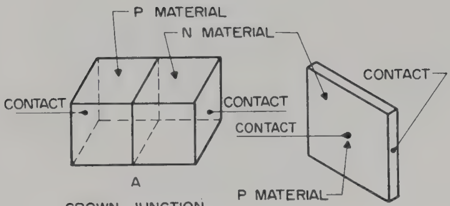
FIRST ALTERNATION

SECOND ALTERNATION

FULL-WAVE RECTIFIER
FIGURE 9



FULL-WAVE BRIDGE RECTIFIER
FIGURE 10



A
GROWN JUNCTION

B
FUSED JUNCTION

JUNCTION DIODE CONSTRUCTION
FIGURE 11

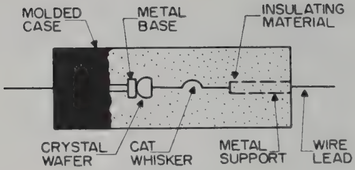
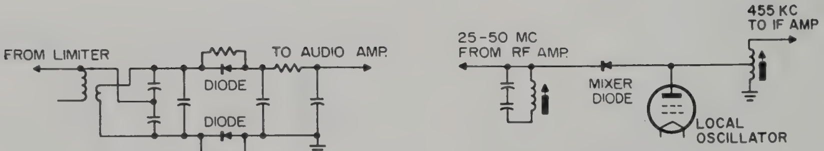


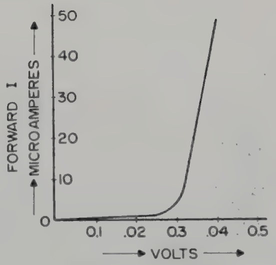
FIGURE 12



DISCRIMINATOR

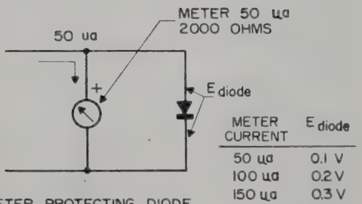
MIXER

FIGURE 13



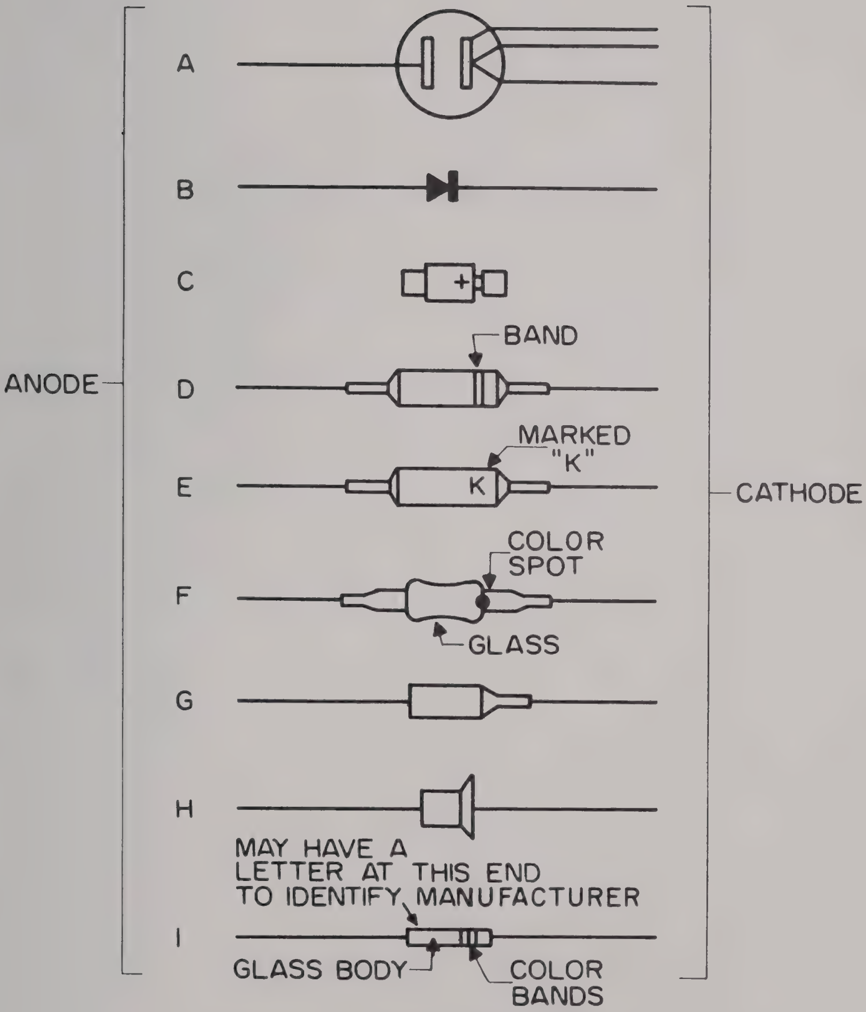
FORWARD CURRENT OF
SILICON JUNCTION DIODE

FIGURE 14



METER CURRENT	E diode
50 ua	0.1 V
100 ua	0.2 V
150 ua	0.3 V

METER PROTECTING DIODE
FIGURE 15



TUBE, GERMANIUM, AND SILICON
DIODES IDENTIFICATION
FIGURE 21

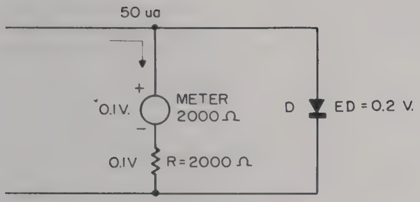


FIGURE 16

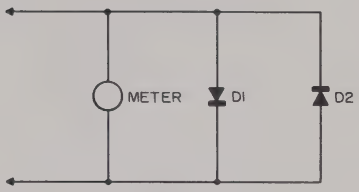
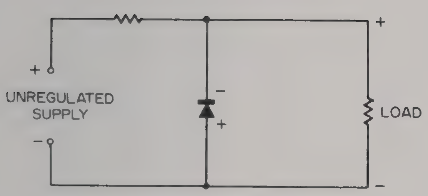


FIGURE 17



ZENER DIODE AS
VOLTAGE REGULATOR

FIGURE 18

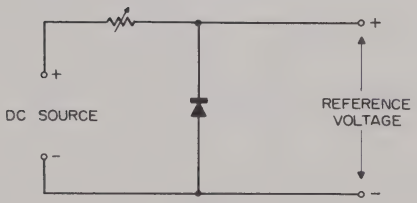


FIGURE 19

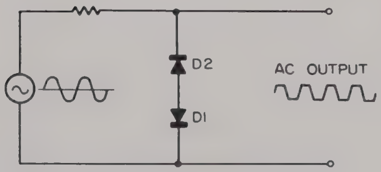


FIGURE 20

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EXAMINATION, LESSON SA-2

1. The junction diode is used in high-current applications. TRUE______ FALSE______.
2. When a junction of P-type and N-type semiconductor material is initially made, holes and electrons cross the junction from one material to the other, leaving positive and negative ions on either side of the junction. TRUE______ FALSE______. The positive fixed ions are in the P material and the negative fixed ions are in the N material. TRUE______ FALSE______
3. Forward bias at the emitter junction reduces the strength of the internal barrier field and encourages current across the junction. In order to constitute forward bias, the positive side of the battery connects to the N-type material and the negative side of the source connects to the P-type material. These statements are:
   A. All true__________ B. Partially true__________ C. All false __________.
4. Figure A shows a semiconductor diode, an ammeter, and a battery.
   (A) Connect the units so that the junction is forward biased and the ammeter indicates the junction current.
   (B) Indicate the polarity of the meter and show the direction of hole movement within the diode.
5. Figure B includes a semiconductor diode, a battery and a voltmeter.
   (A) Connect the battery to reverse bias the diode.
   (B) Connect the voltmeter to measure the amount of reverse bias.
6. As the bias voltage applied to a semiconductor diode is increased, starting at zero, the current remains relatively constant up to a certain voltage, at which time the current suddenly increases to a very high value. From this action, we may dedu that the diode is (forward) (reverse) biased.
7. Figure C is the symbol for a semiconductor diode.
   (A) Indicate which is the P and which is the N material.
   (B) Indicate the direction of electron flow through the junction.
8. Point-contact diodes are generally used where (high-current) (low-current) or (high frequencies) (low frequencies) are involved.
9. Figure D shows a diode placed in parallel with a meter for the purpose of preventing excessive currents through the meter. Current passes through this diode in the (forward) (reverse) direction. This means that the diode (does) (does not) operate according to its Zener characteristics.
10. Figure E includes several diodes which are to be identified as to their cathode and anode. Write "K" by the cathode terminal at each of these diodes.

FIGURE A

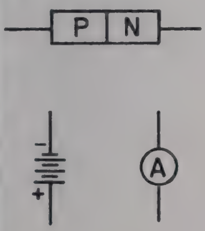


FIGURE B

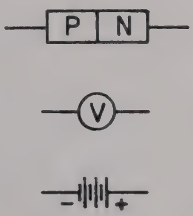


FIGURE C

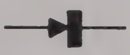


FIGURE D

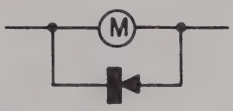
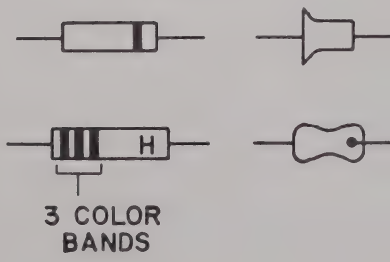


FIGURE E



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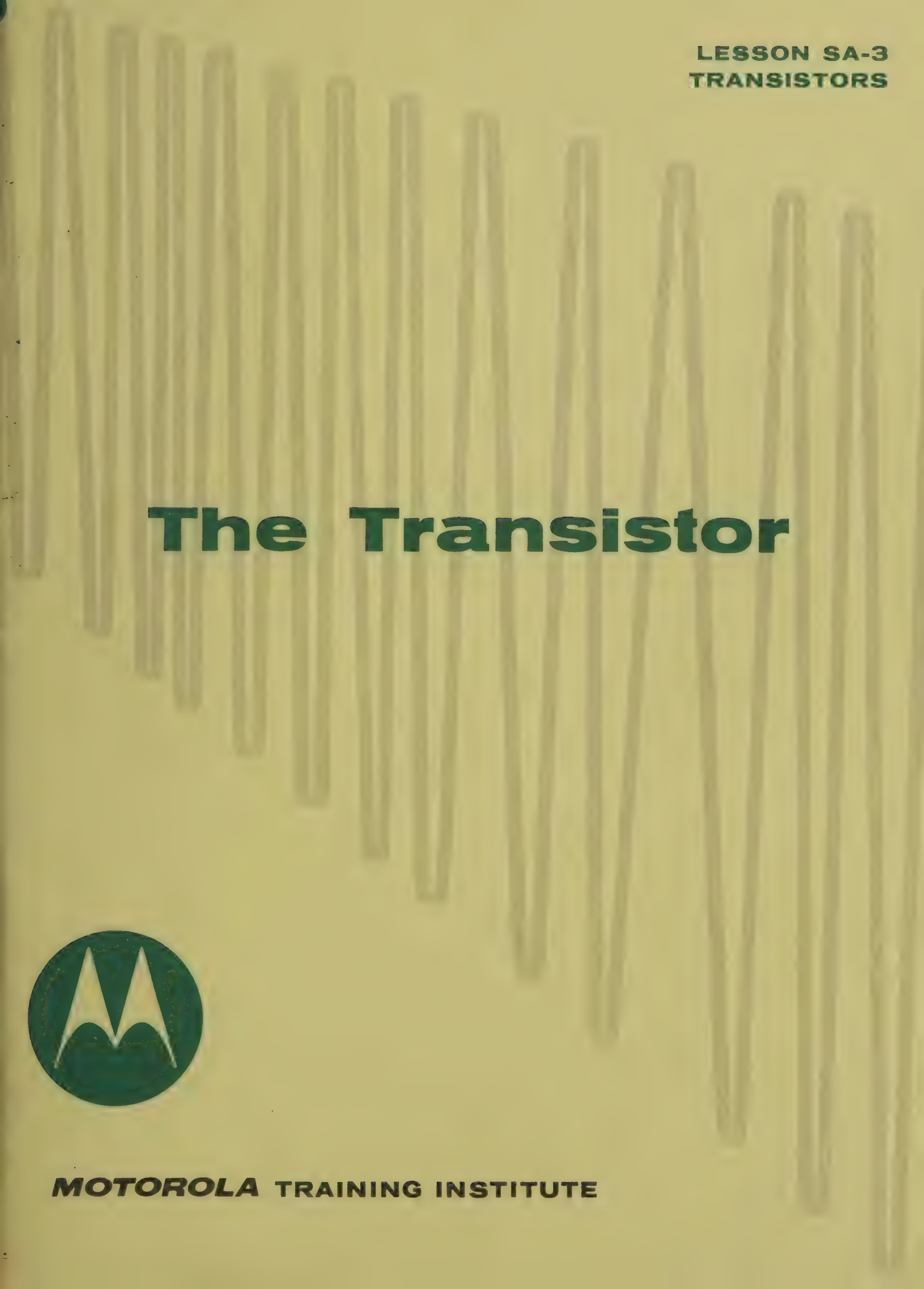
A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON SA-3
TRANSISTORS



The Transistor

MOTOROLA TRAINING INSTITUTE

A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON SA-3
TRANSISTORS

The Transistor

—one of a series of lessons on two-way FM communications—

MOTOROLA TRAINING INSTITUTE
4501 W. AUGUSTA BLVD., CHICAGO 51, ILLINOIS
APPROVED BY THE STATE OF ILLINOIS
DEPT. OF REGISTRATION AND EDUCATION

PREFACE

This is one lesson of a complete Motorola Home-Study Course which presents to the Service Technician both the principles of operation and the maintenance of two-way FM radio systems. The program covers mobile, portable and base station equipment, including the latest transistorized units.

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THE TRANSISTOR

LESSON SA-3

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NOTICE

Diagrams and figures referenced in text are "fold-outs" in back of each lesson, for use while studying. The Examinations are also there.

Communications on oil refining apparatus is best accomplished by transistorized "Handie Talkie" portable radiophones. Maintenance and refining engineers are able to communicate with both refinery headquarters and with personnel working on the structure.

TRANSISTOR CONSTRUCTION AND OPERATION

Lesson SA-3

Introduction

In the two preceding lessons we discussed the conductivity of elements (particularly semiconductors), the doping of germanium and silicon to produce P- and N-type material, the semiconductor diode, and the nature of forward and reverse bias.

In this lesson we shall discuss the transistor, concentrating on its basic construction and operation. We shall be interested mainly in answering the basic questions, "What is a transistor?" and "How does it work?" Let us start with the construction of the transistor.

What Makes A Transistor?

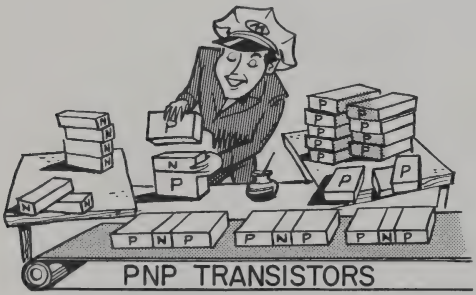
The basic transistor is a three-element semiconductor device consisting of two junctions such as those found in the diodes we have been discussing. This does not mean, however, that a transistor could be made by connecting two such diodes together. Instead, there must be a certain physical relationship between the various elements and junctions. Figure 1 illustrates the construction.

At A, we find a very thin slice of N material sandwiched between two pieces of P material. We have two separate junctions. Starting at the left, we find first a P-N junction and then an N-P junction. The N material is common to both junctions. This middle section is very thin, in the transistor, so that the outer materials (P material) are very close to each other. As we shall see, this is essential if we are to have transistor action.

At figure 1B, we find a second possible transistor combination--a thin slice of P material between two pieces of N Material. Again there are two junctions and the outer materials are physically close to each other. Transistors which resemble the arrangements of figure 1 are called junction transistors; they are constructed in the same general manner as junction diodes.

Figure 1A is commonly called a PNP transistor, and 1B an NPN transistor. The reason for these designations is obvious if we consider the arrangement of the P and N materials.

In the PNP transistor of figure 2A, the P material at the left is considered to be the source of current carriers. That is, in P-type material the holes are the main carriers, so the holes become the source of current in the same manner as the electrons at the cathode of the vacuum tube become the source of tube current. In operation, the holes of the P material at the left move across both junctions and into the P material at the right. This action occurs only when the correct bias voltages are established at the junctions.



Basically, a PNP Transistor Consists of a Thin Portion of N Material Between Two Pieces of P Material.

In the NPN transistor of figure 2B, the electrons within the N material at the left are the majority carriers; they are the source of current. With proper bias at the junctions, these carriers traverse both junctions, establishing current between the outer elements.

One particular type of transistor is said to be fabricated by the "grown" method, the characteristic of the materials being changed from P-type to N-type (or vice versa) as the crystal is grown. Another type of transistor, known as the "alloy junction," is shown in figure 3.

Here we find a thin wafer of N material. Two beads of indium (P impurity material) have been alloyed into opposite sides of the N wafer, by placing the assembly in an oven and heating it. The indium atoms alloy into the surface of the N wafer, producing two junctions within the N material.

When terminal connections are made to the three elements (the two indium beads and the N wafer), we have a practical PNP transistor. (An NPN transistor may be made in the same manner, using a P wafer and two beads of N impurity material.) Most of the PNP transistors found in equipment today are of the alloy junction type.

The principle of operation is essentially the same for the alloy transistor as for the grown junction type.

The Three Transistor Elements

Inspect figure 4A for the names of the three transistor elements. We said that the one at the left is the source of the carriers within the transistor. Thus, we can readily see why this element is called the "emitter."

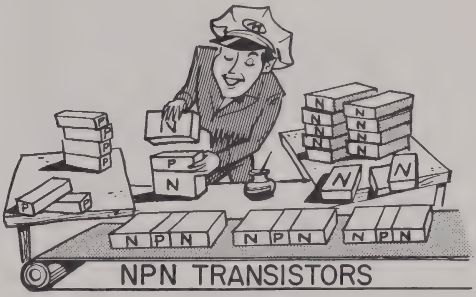
We also said that the carriers within the transistor cross both junctions to enter the right-hand section of the unit--hence, the term "collector" is appropriate for this portion of the transistor. The third element, the center, is call the "base."

These terms apply equally well to the PNP transistor at figure 4B. The source is the emitter, the middle element is the base, and the third part is the collector. The emitter of the NPN transistor 4A is N material, the base is P material, and the collector is N material. In this transistor, current is considered to be the result of electron conduction. In PNP units the emitter, base and collector are P, N and P material, respectively, and the conduction is due to the movement of holes.[1]

Junction Bias

Figure 5 shows the two junctions within the transistor. These are the emitter-base and the collector-base junctions. We often refer to them as just "emitter junction" or "collector junction," respectively.

If the emitter is to become the source of "carriers" it is necessary to bias the emitter junction in the forward direction. (The action is similar to that already discussed in the preceding lesson dealing with diode junction bias.) Forward emitter junction bias is shown in figure 6.



Basically, an NPN Transistor is Made by Sandwiching a Thin Slice of P Material Between Two N Areas.

At figure 6A, the holes--the carriers of the emitter--readily move across the emitter-base junction and enter the base region, for the base is negative with respect to the emitter and the resulting field causes the carriers (holes) to cross the junction and enter the base region. Once inside the base, however, the movement of these carriers is somewhat haphazard and they "diffuse" throughout the entire base region.

With no additional voltages applied to the transistor, the holes eventually reach the external base circuit, becoming emitter-base current. As we shall soon see, however, this is not what happens when the proper bias is established at the collector-base junction.

Before we proceed with collector junction bias, however, let us look at figure 6B, which shows forward bias at the emitter-base junction of an NPN transistor. Here the battery voltage makes the N emitter negative with respect to the P base, releasing the free electrons (the carriers) of the emitter into the base. The only difference here is that current is due mainly to electron conduction while hole conduction is the nature of the current in the PNP transistor (at figure 6A).

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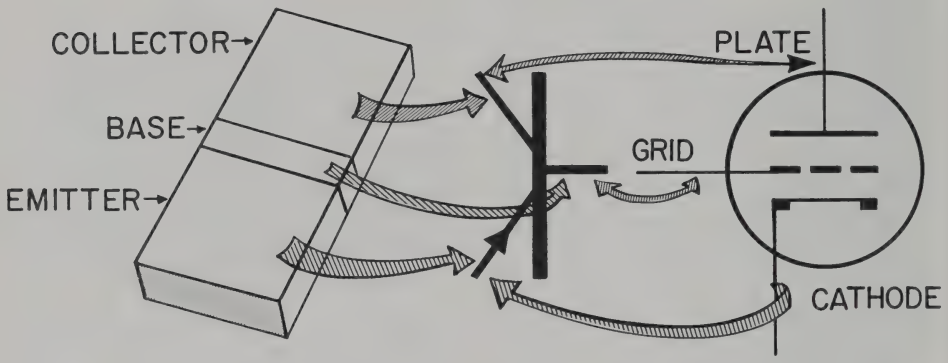
1. See Basic Theory and Application of Transistors (TM11-690) pages 36-39.



Here We See a Comparison of the Transistor Elements With Those of the Vacuum Tube.

Figure 7 shows the normal bias for the collector-base junction--in the reverse direction. The collector-base current is thus extremely small--practically zero. This is desirable. (The ability of reverse bias to discourage junction current has already been analyzed in our discussion of diodes.)

Now that we have given separate consideration to the forward bias of the emitter-base junction and to the reverse bias of the collector-base junction, we are ready to determine what really happens when these two biases are applied simultaneously to the transistor.

Transistor Currents

Figure 8 shows a PNP transistor with the emitter forward biased and the collector reverse biased. The forward bias of the emitter drives the holes (the carriers in a P-type emitter) across the junction and they diffuse throughout the base. Instead of reaching the base to establish an emitter-base current, however, most of the holes are captured by the collector and constitute a current from emitter to collector.

There are several reasons why the holes (the carriers from the emitter) are captured by the collector instead of the base. In the first place, the collector junction area is larger than that of the emitter--it more or less "surrounds" the emitter. (See figure 8.) In the second place, the base material is very thin between the emitter and collector, with the result that the holes entering the base do not travel very far from the junction before they encounter the electric field established at the collector-base junction by the collector-base bias.

Another reason for the large emitter-to-collector current is that the emitter material is heavily doped with impurity atoms; the N-type base material is not. This means that there are many more holes crossing the emitter junction into the base than there are free electrons in the base which can combine with the holes. As a result, most of the holes continue to wander through the base until they encounter the electric field at the collector junction.

Thus, because most of the carriers from the emitter are captured by the collector and only a small number of them reach the base terminal, the collector current will be almost as large as the emitter current and the base current will be very small.

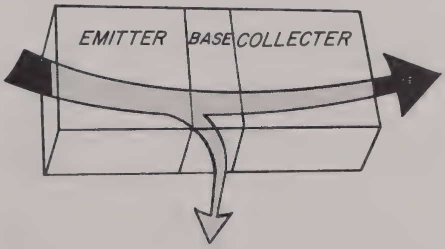
At first consideration of figure 8 it may appear that the reverse bias at the collector would prevent collector current. In fact, this is true so far as collector-to-base current is concerned. Insofar as the holes originating at the emitter but now drifting through the base are concerned, however, the collector junction bias actually encourages these holes to cross the collector junction.

Thus it is that the polarity of the collector bias (the direction of the field established by this bias) encourages holes to move from the base region to the collector. We must remember that these holes in the base are not always present in the N material; on the contrary, they start at the emitter (with the emitter junction forward biased), cross the emitter junction, and diffuse throughout the base area. The holes from the emitter (now in the base) are next pulled across the collector junction, establishing emitter-collector current.

In the absence of any emitter current, however, there are no holes (carriers) released into the base from the emitter, so there can be no collector current; collector current is dependent upon and controlled by emitter current.

Brief Review

Let us summarize briefly the main points which we have already learned about the transistor. With biases as shown in figure 8, a large number of holes leave the emitter, cross the junction and enter the base material. Also, there are many more positive holes available in the emitter than there are electrons in the base. As a result, very few of the holes are captured within the base as base current. Instead, most holes encounter the field produced by the collector bias and are swept across the collector junction.



Current Through the Transistor--From the Emitter to the Collector--is Dependent Upon and Controlled by a Smaller Emitter-Base Current.

The collector current is almost as great as the emitter current; the base current is very small compared to the collector current. Collector current, since it depends upon emitter current, is readily controlled by the emitter current; emitter current, in turn, may be regulated by the emitter-base bias.

Transistor Symbols

Figure 9 shows various semiconductor symbols which have been standardized by the IRE and adopted by the EIA. Figure 9A shows the base symbol. The horizontal line is the base proper and the perpendicular line is the base connection. From this symbol it is impossible to know whether this is N material or P material. This can be determined only after the emitter symbol has been added, as shown in 9B and 9C.

At B we find a slanted line (representing the emitter) meeting the base line. This slanted line also carries an arrow and the arrow points toward the base, indicating the emitter is P material. The slant signifies that the base must be composed of the opposite type material, so if we have a P emitter, we have an N base. At C the emitter arrow points away from the base, so we have an N emitter (and a P base).

The slanted line at D (with no arrow) represents a collector--again the slant signifies that the collector material is dissimilar to that of the base. Thus, if the base is P, the collector is N, and vice versa.

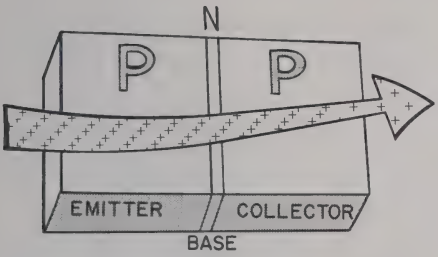
Figure 10 shows the complete symbols for both PNP and NPN transistors. At 10A the emitter arrow points toward the base line, so this is a PNP unit. At 10B the emitter arrow points away from the base line; this is an NPN unit.

Transistor Action

We have already seen that the collector current in the transistor depends upon the release of carriers from the emitter into the base. This, in turn, is determined by the emitter junction bias. While the bias for the emitter junction is often stated in terms of the voltage applied from an external source, it is well that we also think of this bias in terms of the current established at the junction.

The emitter current divides into two separate currents--the collector current and the base current. It is normal for at least 95% of the emitter current to become collector current, resulting in a relatively small base current. Thus, the collector current is many times greater than the base current, and their ratio is often used to express the current "gain" of a transistor.

Let us assume that a transistor is being used as an amplifier--also, that normal forward bias has been established for the emitter junction, and that the collector junction is reverse biased. An external signal is applied, and this



For PNP Transistors, Current is Due Mainly to the Movement of Positive Carriers (Holes) From the Emitter to the Collector.

signal causes small changes in base current. As a result, larger changes occur in the collector current. (We shall see the specific circuits later.)

The ability of the transistor to produce large changes in collector current as a result of small changes in emitter-base current is one of the factors contributing to the ability of the transistor to amplify. Another important factor which enables a transistor to provide gain is its high collector (output) impedance compared to its low emitter-base (input) impedance. More will be said about this in later lessons.

Transistor Circuits

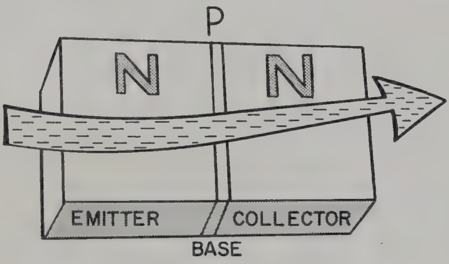
When analyzing the various configurations associated with the transistor, it is permissible to make certain comparisons with vacuum tube circuits. While the emitter, base and collector are by no means identical to the cathode, grid and plate (respectively) of the vacuum tube, they exercise somewhat similar functions. The units are compared in figure 11.

At A we find the triode tube symbol, at B we see the pictorial representation of the transistor we have been using, and at C we have the transistor symbol. (This, of course, could be an NPN as well as the PNP unit shown.) The emitter serves the same purpose as the cathode--it becomes the source of current carriers for the device. The collector is similar in function to the plate, and the base is somewhat similar to the grid.

A basic comparison may be made of the action of the transistor and that of the vacuum tube. In the vacuum tube, the grid-cathode voltage (bias) is used to control the plate current (cathode-plate current). In the transistor, the emitter-base bias becomes the factor which controls the collector current (emitter-collector current). We must always remember that emitter-base bias refers more specifically to the emitter-base current than it does to the applied external voltage.

Small variations of the grid-cathode bias voltage in the vacuum tube causes comparatively large changes of the plate current. In a similar manner, small changes of the emitter-base current means large changes of collector current. For this reason, we often refer to the vacuum tube as a voltage controlling device, but to the transistor as a current controlling device.

Figure 12 shows a popular vacuum tube circuit, the grounded cathode; the signal is applied between grid and ground, and the output is taken from the plate circuit. The corresponding transistor circuit shows the emitter grounded, with the signal applied between base and ground and with the output secured at the collector. The biasing circuits have been eliminated from both the tube and transistor circuits for simplicity.



For NPN Transistors, Current is the Result of Electrons Leaving the Emitter and Crossing the Base Into The Collector

We usually refer to the arrangement of figure 12 as a "common emitter" circuit rather than a grounded emitter. A resistor and capacitor are often included between emitter and ground--then, although the emitter is no longer "grounded," it is still common to the input and output circuits.

Figure 13 shows another tube circuit, this time a grounded-grid amplifier. The corresponding transistor circuit, which is also shown, is termed a "common base" circuit, for the base is common to the input and output. In the vacuum-tube arrangement, the signal is applied to the cathode and the output is taken from the plate circuit. In the transistor arrangement, the input is to the emitter and the output is taken from the collector.

A third familiar vacuum-tube circuit is the "cathode follower" or "grounded plate" circuit of figure 14. The signal is applied to the grid and the output taken from the cathode. The corresponding transistor circuit is the "common collector" arrangement in which the input is applied to the base and the output is taken from the emitter. In this circuit, the collector is common to both the input and the output.

The Common-Emitter Circuit

The circuit of figure 15 shows a common-emitter transistor amplifier. A 6-volt battery is used both for the forward bias of the emitter junction and for the reverse bias of the collector. This is accomplished by grounding the positive side of the battery, so that the grounded emitter is the most positive point of the circuit. The collector connects to the negative side of the battery through a resistor, RC, and for convenience we have assumed that collector current causes a drop of 4 volts across this resistor. This means that the voltage between the collector and ground is two volts, the collector side being negative.

Forward bias of the emitter junction is obtained by means of a voltage divider (R1 and R2) across the battery, the base being connected to the tap on the divider.

(The drop across R2 is 0.2 volt.) With the emitter grounded and with the base at -0.2 volt with respect to ground, a forward bias of 0.2 volt is obtained--a typical value for many transistors.

The collector junction is reverse biased by virtue of the collector being more negative than the base. The collector is -2 volts with respect to ground and the base is -0.2 volt with respect to ground, resulting in a net reverse bias of 1.8 volts between collector and base. We are now ready to see what happens when a signal is applied.

Common-Emitter Phase Relationships

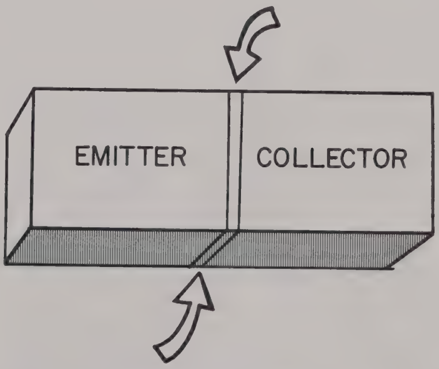
Figure 16 shows the phase relationship between the input and output waveforms for the positive half-cycle of the input signal. The initial voltages applied to the various transistor elements are the same as in figure 15.

During the first alternation, the input signal varies from zero to a positive 0.1 volt and then back to zero. When this signal is superimposed upon the base-ground circuit of the transistor, it causes the base-emitter voltage to change from its normal value of -0.2 volt to -0.1 volt. This decreases the forward bias and, as a result, the collector current as well as the voltage drop across the collector resistor must decrease.

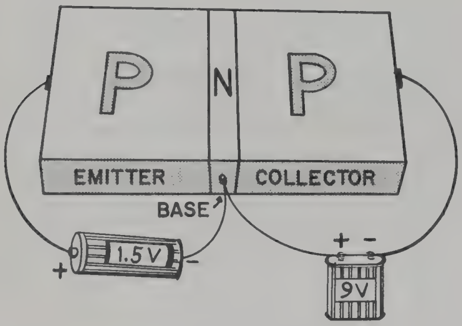
We previously assumed that the voltage across RC was 4 volts. We shall now assume further that the voltage drop across the resistor decreases to 3 volts. As a result, the collector voltage (with respect to ground) changes from -2 volts to -3 volts. At the output (on the other side of the coupling capacitor), the DC component is removed by the capacitor and all that remains is the 1-volt change in the negative direction.

Thus, for an input signal which swings in the positive direction, the output voltage swings in a negative direction. This indicates that there is a phase reversal of 180° in the common-emitter circuit. Let's see if this reversal also holds true for a negative swing of the input signal.

Figure 17 indicates the action of the same common-emitter amplifier during the negative alternation of the input signal. The input



In a Transistor the Base Region Between the Two Junctions is Normally Less Than .001 Inch Thick.



Normal Bias of a PNP Transistor Demands a Positive Emitter and a Negative Collector, Both With Respect to the Base.

swings 0.1 volt negative and causes a change of base voltage from -0.2 volt to -0.3 volt. This is an increase of the forward bias, and the transistor currents increase. The increase of collector current through the collector resistor causes a greater voltage drop, and we have assumed the increase is from 4 to 5 volts. The voltage at the collector with respect to ground has then changed from -2 volts to -1 volt. At the output, the coupling capacitor has removed the DC component and the output has swung 1 volt in the positive direction.

From this action we see that the output voltage of the common-emitter circuit is 180° out of phase during the negative swing of the input signal as well as for the positive swing. We may thus generalize, saying that the common-emitter circuit produces a 180° phase shift in the output signal.

We have assumed that the input signal of 0.1 volt in figures 16 and 17 causes changes of 1 volt at the output. Thus, the voltage amplification of 10 has been realized. In practical circuits, gains even greater than 10 are possible, particularly at low frequencies and for limited bandwidth circuits.

The term "gain," as we use it here, applies strictly to the ratio between the output and input voltages. In many discussions on transistors, gain is a term reserved for the power relationship of the output to the input, and "amplification" is used for either the voltage or the current ratios. We shall have more to say on this subject in a later lesson.

Figures 16 and 17 make use of a PNP transistor. For a comparable NPN circuit, the only noticeable differences in the circuit is that the polarity of the battery and circuit voltages are reversed. A positive swing at the input will still cause a swing in the negative direction at the output, and vice versa.

The Common-Base Circuit

Figure 18 is a simplified arrangement of a common-base transistor amplifier stage. We are interested mainly in the operating voltages and the phase relationship of the input and output signals.

Two separate batteries supply the proper bias at the junctions of the PNP-type transistor in figure

18. The grounded base is common to the input and output circuits, which is the reason for the designation "common base."

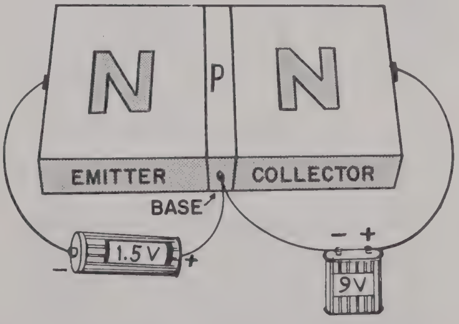
The emitter is forward biased by the 1.5 volt battery, the current at the emitter junction being limited to the correct value by emitter resistor RE. The emitter is 0.2 volt positive with respect to the base, and for a PNP transistor this constitutes a typical forward bias.

The collector junction is biased in the expected reverse direction by the 6-volt battery. As a result of emitter-collector current through the collector resistor (RC), there is a 4-volt drop across the resistor and the collector is two volts negative with respect to the base. These are the established DC values for the transistor before a signal is applied. Let's see what happens when a signal reaches the emitter.

A positive input signal to the emitter makes the emitter more positive with respect to the base and increases (1) the forward bias, (2) the collector current, and (3) the drop across the collector resistor. As a result of this increased drop, the collector becomes less negative with respect to ground. This is effectively the same as going positive and, at the output, the swing is from zero to some positive voltage. From this action we see that the output voltage swings in the same direction as the input signal; there is no phase change between input and output.

During the negative half-cycle of the input voltage at figure 18, the opposite action takes place. The emitter becomes less positive, decreasing the forward bias. The collector current decreases and so does the voltage across the collector resistor. This means that the collector is now more negative with respect to ground and the output swings in the negative direction. Thus, on both the positive and the negative alternation, the output has the same phase as the input.

The fact that the common-base circuit of figure 18 causes no phase change in the output and input signals is not a function of the type of transistor used; instead, it is a function of the nature of the circuit itself. An NPN transistor used as an amplifier in a common-base circuit will also produce signals at the output which are in phase with those of the input.

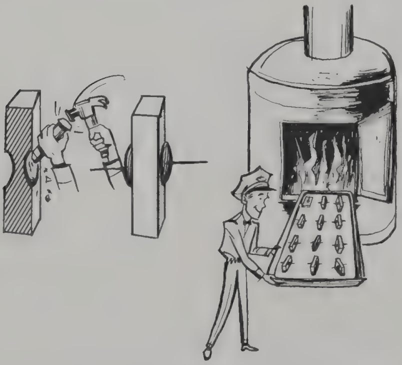


For an NPN Transistor, the Emitter Should be Made Negative to the Base and the Collector Should be Positive.

The values chosen for the analysis of figure 18 are the same as those of figures 16 and 17. This was done for convenience and does not necessarily imply that the gain of this circuit will be the same as that of the common-emitter circuit. Comparative gains of transistor circuits will be discussed later.

The Common-Collector Circuit

The common-collector circuit of figure 19 is electrically the same as that of figure 14, but the circuit has been redrawn in order to allow the collector to appear at the lower portion of the figure. To facilitate grounding the collector, the negative side of the battery is grounded and the positive side connected to the emitter through load resistor RE. Forward bias is provided by using a voltage divider (R1 and R2) across the battery and connecting the base at the midpoint. The resistance values are chosen so that the emitter is 0.2 volt positive with respect to the base.



In Actual Transistor Construction, Wells are Made in the Sides of the Base. Emitter and Collector Materials are Next Placed in the Wells. The Entire Assembly is Then Heated to a Specific Temperature for a Predetermined Length of Time.

The positive half-cycle of the input signal swings the base more positive, lowering the forward bias and causing the emitter current to decrease. With less current through the emitter resistor, the voltage drop is also less and the emitter becomes more positive with respect to ground--this is a positive swing of the output voltage.

During the negative portion of the input voltage swing, the base is driven negative (less positive), increasing (1) the forward bias of the base-emitter junction, (2) the emitter current through the emitter resistor, and (3) the voltage drop across the resistor. The emitter is now less positive with respect to ground and the output swings negative.

During each alternation of the input signal, the output voltage changes in the same direction. This means that the input and output are in phase; there is no phase reversal.[2]

Summary

In this lesson we have learned about the general construction of the grown junction and alloy type transistors. Transistors may be constructed either "PNP" or "NPN," the letters indicating the material used for the emitter, base, and collector, respectively.

---

[2] See TM11-690, pages 42-51.

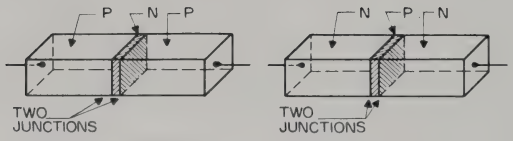
Transistors usually have their emitter-base junction biased in the forward direction and their collector-base junction reverse biased. Forward emitter bias produces a certain amount of emitter current, most of which appears as emitter-collector current and very little of which becomes emitter-base current. The reverse bias of the collector junction prevents any appreciable amount of collector-base current.

The ability of the transistor to amplify depends to a considerable extent upon the ability of a small variation in the base current to cause a larger change in the collector current. (More will be said about this in the next lesson.)

In this lesson we also discussed the standard symbols used for transistors, and we learned how the transistor resembles the triode vacuum tube in some respects. We found that there are three main transistor circuits, namely, the common emitter, the common collector, and the common base. The latter two, common base and common collector, provide an output waveform which has the same phase as the input. The common-emitter arrangement, however, causes a phase reversal (180°) between the output and the input.

STUDENT NOTES

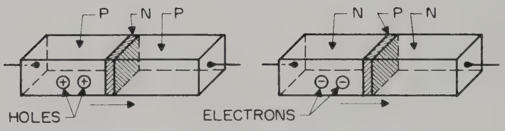
STUDENT NOTES



PNP TRANSISTOR
(A)

NPN TRANSISTOR
(B)

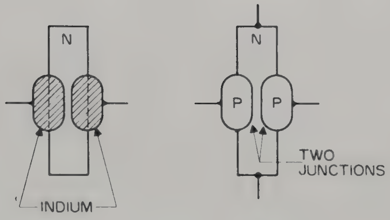
FIGURE 1



PNP TRANSISTOR
(A)

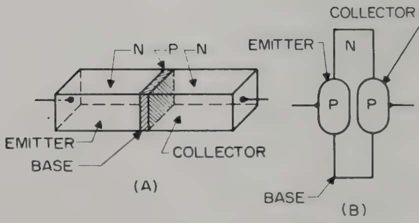
NPN TRANSISTOR
(B)

FIGURE 2



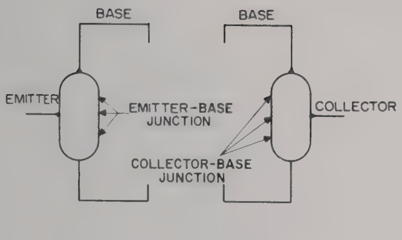
ALLOY JUNCTION TRANSISTOR

FIGURE 3



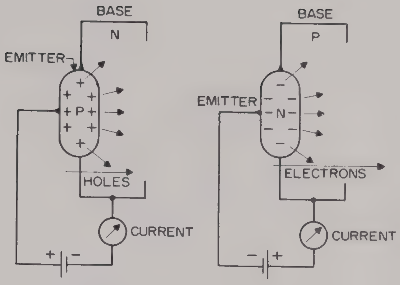
THE THREE ELEMENTS

FIGURE 4



(A) (B)

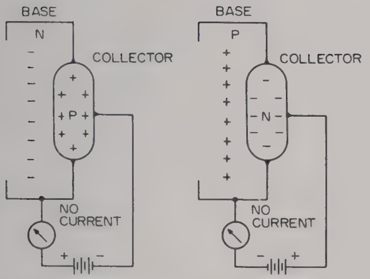
FIGURE 5



P-N JUNCTION
(A)

N-P JUNCTION
(B)

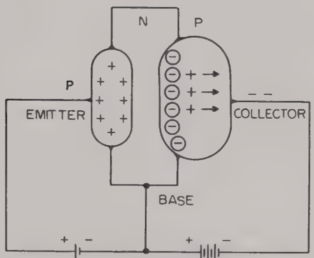
FORWARD
EMITTER-BASE BIAS
FIGURE 6



N-P JUNCTION
(A)

P-N JUNCTION
(B)

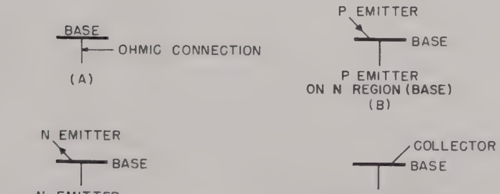
REVERSE COLLECTOR-BASE BIAS
FIGURE 7



EMITTER - BASE
FORWARD BIAS

COLLECTOR BASE
REVERSE BIAS

NORMAL TRANSISTOR BIAS
FIGURE 8



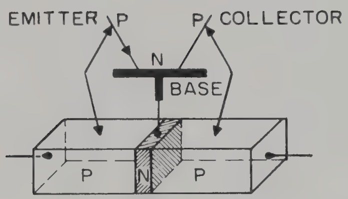
(A)

P EMITTER
ON N REGION (BASE)
(B)

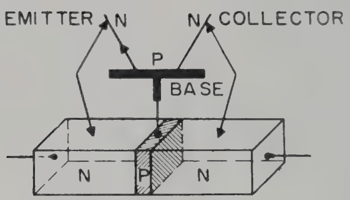
N EMITTER
ON P REGION (BASE)
(C)

COLLECTOR ON SEMI-
CONDUCTOR OF DISSIMILAR
CONDUCTIVITY TYPE
(D)

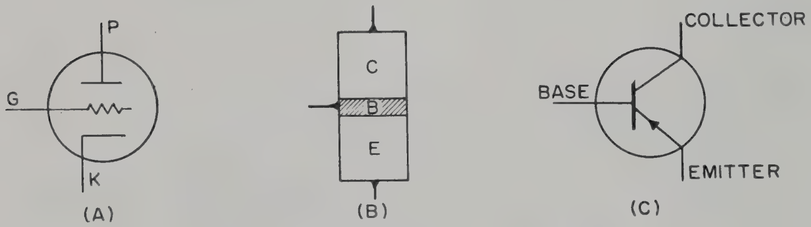
TRANSISTOR SYMBOLS
FIGURE 9



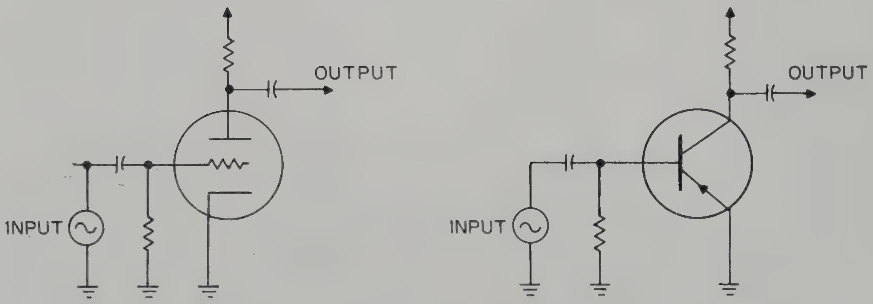
SYMBOL PNP TRANSISTOR
FIGURE 10A



SYMBOL NPN TRANSISTOR
FIGURE 10B



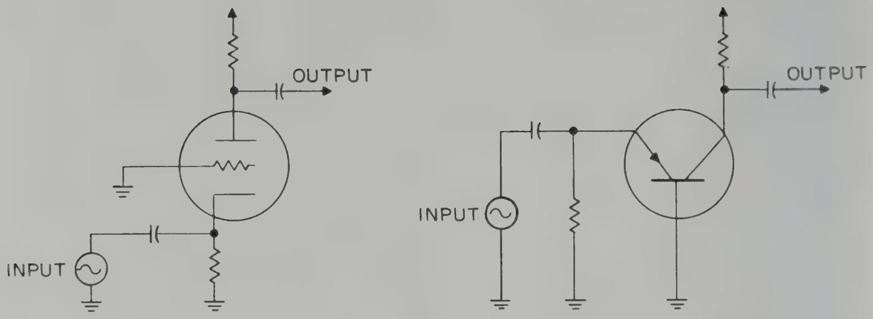
VACUUM TUBE–TRANSISTOR ELEMENTS
FIGURE 11



GROUNDED CATHODE

COMMON EMITTER

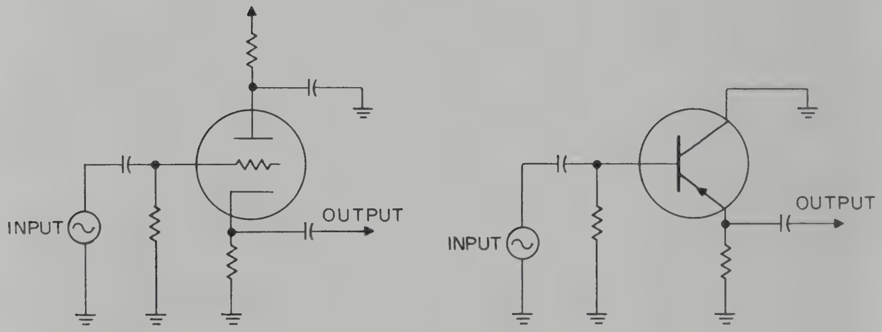
FIGURE 12



GROUNDED GRID

COMMON BASE

FIGURE 13



CATHODE FOLLOWER

COMMON COLLECTOR

FIGURE 14

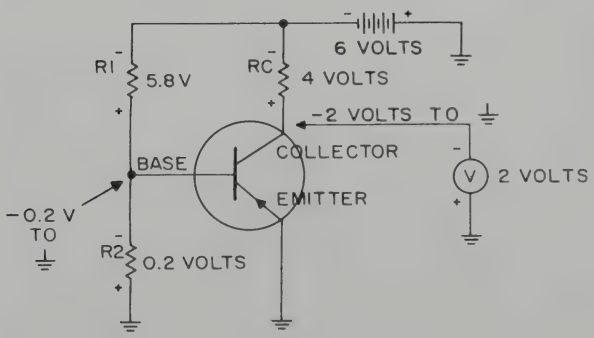
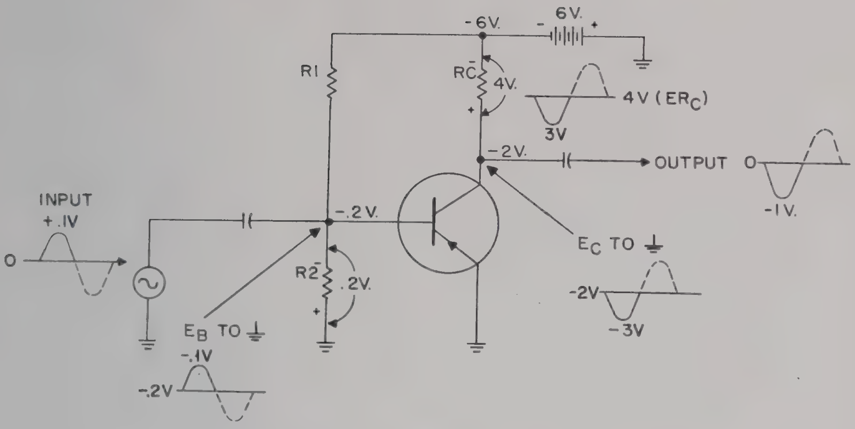


FIGURE 15

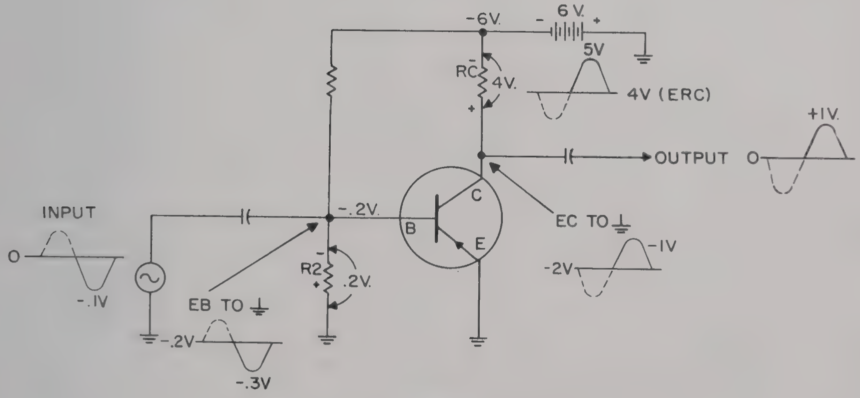


ACTION

1. FORWARD BIAS DECREASES
2. COLLECTOR I "
3. VOLTAGE ERC "
4. COLLECTOR SWINGS MORE NEGATIVE
5. OUTPUT SWINGS NEGATIVE

PHASE REVERSAL–
COMMON EMITTER CIRCUIT
(POSITIVE ALTERNATION)

FIGURE 16

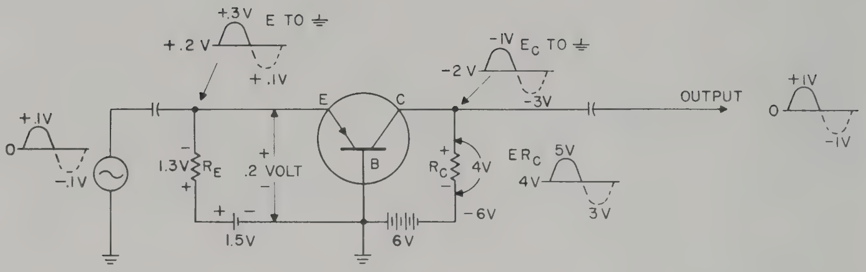


ACTION

1. FORWARD BIAS INCREASE
2. COLLECTOR I "
3. VOLTAGE ERC "
4. COLLECTOR TO ⏚ SWINGS LESS NEGATIVE
5. OUTPUT SWINGS POSITIVE.

PHASE REVERSAL OF
COMMON EMITTER CIRCUIT
(NEGATIVE ALTERNATION)

FIGURE 17

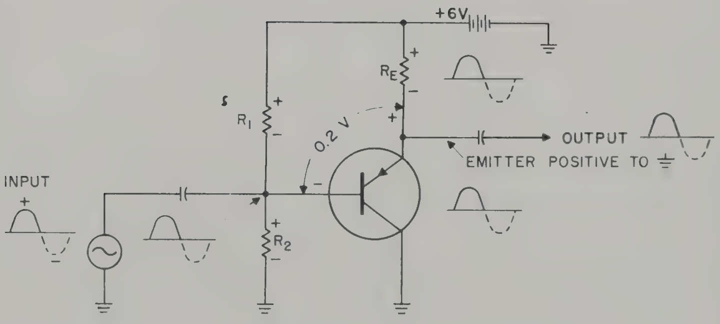


ACTION

	"+" ALTERNATION	"-" ALTERNATION
1.	FORWARD BIAS INCR.	FORWARD BIAS DEC.
2.	COLLECTOR I INCR.	COLLECTOR I DEC.
3.	E OF R_C INCR.	E OF R_C DEC.
4.	E_C TO ⏚ GOES +	E_C TO ⏚ GOES -
5.	OUTPUT SWINGS +	OUTPUT SWINGS -

COMMON BASE CIRCUIT
PHASE RELATIONSHIP

FIGURE 18



	"+" ALTERNATION	"-" ALTERNATION
1.	FORWARD BIAS ↓	FORWARD BIAS ↑
2.	EMITTER-CURRENT ↓	I_E ↑
3.	E R_E ↓	E R_E ↑
4.	E_E TO ⏚ GOES +	E_E TO ⏚ GOES NEG.
5.	OUTPUT GOES +	OUTPUT GOES NEG.

PHASE RELATIONSHIPS
COMMON COLLECTOR

FIGURE 19

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EXAMINATION, LESSON SA-3

1. The transistor is basically a (two) (three) (four) element semiconductor device. A typical transistor might be identified as (PNN) (NPP) (NNP) (NPN) (PPN).

2. Some transistors are classified as a PNP type, the letters designating the materials of the emitter, base and collector, respectively. For a PNP transistor, then, the emitter and collector are made of "positive" material and the base of "negative" material. These statements are:
A. All correct _______ B. Partially correct _______ C. All wrong _______

3. Match the following columns, comparing the elements of the transistor to those of the vacuum-tube triode.

Vacuum Tube	Transistor
A. Grid	_______ Emitter
B. Plate	_______ Collector
C. Cathode	_______ Base

4. In figures A and B, connect the batteries for forward bias at the emitter junctions.

5. In figure C, the emitter junction has (forward bias) (reverse bias) and the collector junction has (forward bias) (reverse bias).

6. In normal transistor action, the carriers which make up collector current originate at the (emitter) (base). In order for these carriers to pass into the collector region, the collector-base junction must be (forward) (reverse) biased. The amount of base current is (small) (about the same) (large), compared to the emitter current.

7. In a transistor circuit, the collector current is controlled mainly by: (Choose one answer.)
A. The collector _____ C. The collector-base voltage _____
B. The emitter junction bias _____ D. None of these _____

8. Fill the blanks in the following statements with "E", "C", or "B", to indicate the emitter, collector or base, whichever applies.
In a PNP transistor, the _____ is made of negative material. In normal operation the _____ is positive with respect to the base and the _____ is negative with respect to the base. The greatest current will appear in the _____ circuit, and the _____ circuit will have the least current. With proper bias voltages, carriers leave the _____ and enter the _____ region. They then diffuse through the _____ region until they encounter the field at the _____-base junction. This field sweeps the carriers into the _____.

9. Figure D is a (common-emitter) (common-base) (common-collector) transistor circuit. The emitter is forward biased by battery (E1) (E2). The collector is (forward) (reverse) biased. This is a (PNP) (NPN) type transistor.

10. Figure E shows (a PNP) (an NPN) transistor with the (emitter) (collector) (base) grounded. The emitter is forward biased by battery (E1) (E2) and the collector is (forward) (reverse) biased. This is a (common-emitter) (common-base) (common-collector) circuit.

FIGURE A

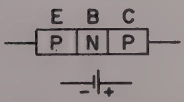


FIGURE B

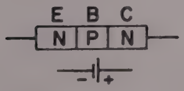


FIGURE C

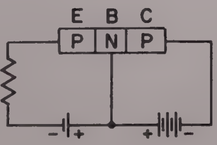


FIGURE D

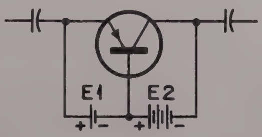
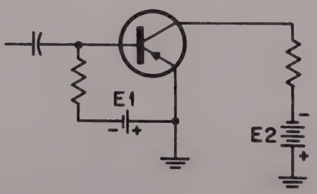


FIGURE E



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TRANSISTORS

Transistor Amplifiers

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LESSON SA-4
TRANSISTORS

Transistor Amplifiers

—one of a series of lessons on two-way FM communications—

MOTOROLA TRAINING INSTITUTE
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PREFACE

This is one lesson of a complete Motorola Home-Study Course which presents to the Service Technician both the principles of operation and the maintenance of two-way FM radio systems The program covers mobile, portable and base station equipment, including the latest transistorized units.

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TRANSISTOR AMPLIFIERS

LESSON SA-4

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NOTICE

Diagrams and figures referenced in text are "fold-outs" in back of each lesson, for use while studying. The Examinations are also there.

Industrial "Dispatcher" radiophone is designed specifically for use on materials handling vehicles such as this fork truck. Radio control of such trucks greatly increases storage and warehousing efficiency.

TRANSISTOR AMPLIFIERS--TYPICAL VALUES

Lesson SA-4

Introduction

In this lesson we shall discuss the transistor amplifier, being especially concerned with the ratio of the collector current to the emitter current or to the base current. In addition to the current gain of the transistor, we are interested in the output resistance or impedance compared with that of the input, for in many circuits this ratio accounts for the stage gain. We shall also see various methods of inter-stage coupling for transistor amplifiers.

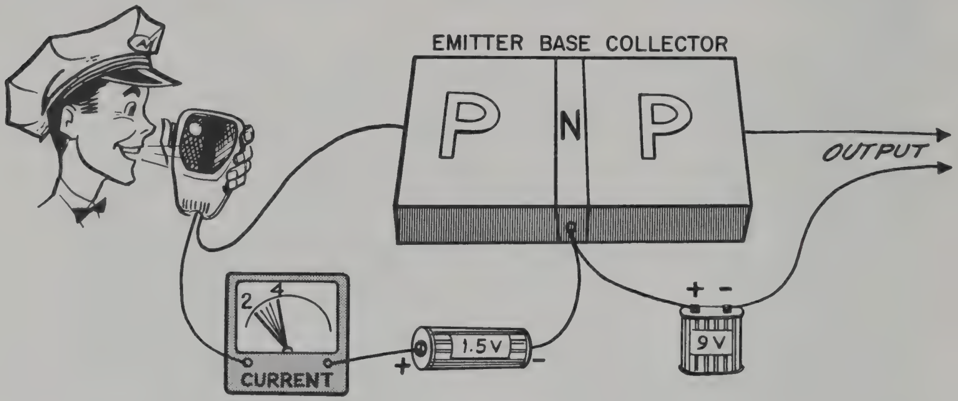
One means of classifying transistors is according to their power capabilities, and in this lesson we shall deal only with low-power devices. (Higher power units, such as those which drive speakers, will be discussed in a later assignment.) These are the things which we are about to study in this assignment. We shall start with the currents in the transistor.

Transistor Currents

Unlike the vacuum tube--which operates on the principle that a small variation of voltage at its input causes a considerable change in plate current--the transistor is not basically concerned with the input voltage. Instead, transistor operation depends upon a changing current at its input junction, for the current at this junction controls the collector current.

When we speak of the transistor input, then, we refer to current variations at the emitter-base junction; although the input may be expressed in terms of the externally applied voltage, we should think of the change of current taking place across the junction.

For the average low-power transistor, 98 per cent or more of the emitter current becomes collector current. This means that only 1 or 2 per cent of the emitter current is left for base current. Figure 1 shows these currents. Here we find a PNP transistor in a common-base configuration, with separate batteries biasing the emitter and collector. The emitter supply is typically low, 1.5 volts. The emitter resistor and the emitter-base section of the transistor are in series and connected across the 1.5 volt battery.



In Transistor Operation, the Current Changes are More Important than the Input Voltages: These Current Changes Control the Output Signal.

Most of this battery voltage appears across the resistor and the balance is the voltage drop across the emitter-base transistor terminals--the 0.2 volt is representative of many low-power units.

The amount of current established at the emitter junction is much more important than the 0.2 voltage drop across the emitter and base terminals. The emitter resistor is chosen to allow the desired amount of current, and in figure 1 this is 1 ma. With normal collector bias, the emitter current divides into 0.98 ma of collector current and 0.02 ma of base current.

One important factor in the operation of the transistor and the amount of collector current should be recognized at this time. Once the collector bias is sufficient that the emitter carriers released into the base are captured by the collector, the value of collector voltage has little effect on the amount of collector current; increasing the collector voltage does not noticeably increase the collector current. Collector current depends primarily upon and is controlled by the emitter current.

Alpha (h_{FB} and h_{fb})

For the common-base circuit of figure 1, the current gain--which we call "alpha" and refer to as " α ", the Greek symbol for alpha --is the ratio of the collector current to the emitter current. (This applies only to the condition where the collector load impedance is zero.) For the values of figure 1, then, alpha is equal to 0.98 divided by 1, or 0.98. In the common-base circuit, the input (emitter) current is always greater than the output (collector) current, which means that the value of alpha will always be less than unity (1).

The term alpha was originally established to express the current relationships of the common-base circuit, and there may be some confusion as to whether this applies to DC currents or to AC currents. Thus, in order to differentiate between them, we now use the expressions "h_{FB}" and "h_{fb}," respectively, the "B" indicating a common base circuit and the capital or small letters referring either to DC or to AC.

The DC current gain h_{FB} also indicates the approximate current gain (of the common-base circuit) for large signal inputs. While the values assumed above are for the DC considerations of figure I, the same results are evidenced if we consider an input signal of sufficient amplitude to swing the emitter current between zero and 1 ma. The corresponding change of collector currentwill be from zero to 0.98 ma. Here we have a change of 1 ma at the input causing a change of 0.98 ma in the output; the ratio of the change in output current to the change of input current is .98.

The current gain (h_{fb}) for small signal inputs will be nearly the same as the DC current ratio so long as the stage operates on the linear or straight portion of its characteristic curve. If the small signal operates over some other portion of the curve, however, the gain will vary with the steepness or "slope" of the curve.

From our discussion this far it may seem impossible to secure any amplification or gain from the transistor, for the output current does not vary as much as the input current. As we shall soon see, however, the input resistance (or impedance) is low while that of the output is considerably higher. This provides voltage amplification and power gain in the stage. Before discussing this further, however, it is well that we first look at the current relationships of other transistor circuits.

Beta (h_{FE} and h_{fe})

Figure 2 shows the circuit of a common-emitter amplifier, and we have assumed the same values used in figure 1: the emitter current is 1 ma, the base current is 0.02 ma, and the collector current is 0.98 ma. Before we discuss the current gain of this circuit, however, we shall study the biasing arrangement, for only one battery is used to provide both the forward emitter bias and the reverse collector bias.

Disregarding the meter in the emitter circuit, the emitter is connected to the positive side of the battery and is the most positive point in the circuit--all other points will be negative (less positive) by comparison. Forward emitter bias is secured by connecting the base return to the midpoint of R1 and R2. The bias voltage is then the voltage across R1 minus the voltage drop across base resistor RB. We will assume that the net voltage between the base and emitter is 0.2 volt, the same as for figure 1.

Reverse collector bias is provided by returning the collector load resistor (RC) to the negative side of the battery, which is "ground" in figure 2. Although both the base and the collector are negative with respect to the emitter, the collector is negative (less positive) compared to the base and hence is reverse biased.

For the common-emitter circuit, the input current includes just the base current--not the entire emitter current. Thus, the input current is very small compared to the output or collector current, and the current gain is the ratio of the collector current to the base current. For the common-emitter circuit of figure 2, the current gain, which was originally called Beta (β), is 0.98 divided by 0.02, or 49. This is the DC current gain, so we use the designation h_{FE}, the capital "FE" indicating DC currents and the "E" indicating a common-emitter circuit. In addition, this rating is for the condition of a short-circuit load at the output.

From the values of figure 2, then, we may deduce that a change of but .02 ma at the input (from 0 to 0.02 ma) can cause a change of 0.98 ma at the output, a gain of 49. This is the current gain of the common-emitter circuit for large signal inputs. The current gain for small signals is designated h_{fe}.

Current gains for this circuit range from low values of around 20 to values in excess of 200.

Alpha-Beta Conversions

There are definite relationships between the alpha (α) and beta (β) current ratings of a transistor which allow a direct conversion from one to the other. The conversion formulas are as follows:

$$(1) \quad \beta \quad (h_{FE}) = \frac{\alpha}{1 - \alpha}$$

$$(2) \quad \alpha \quad (h_{FB}) = \frac{\beta}{1 + \beta}$$

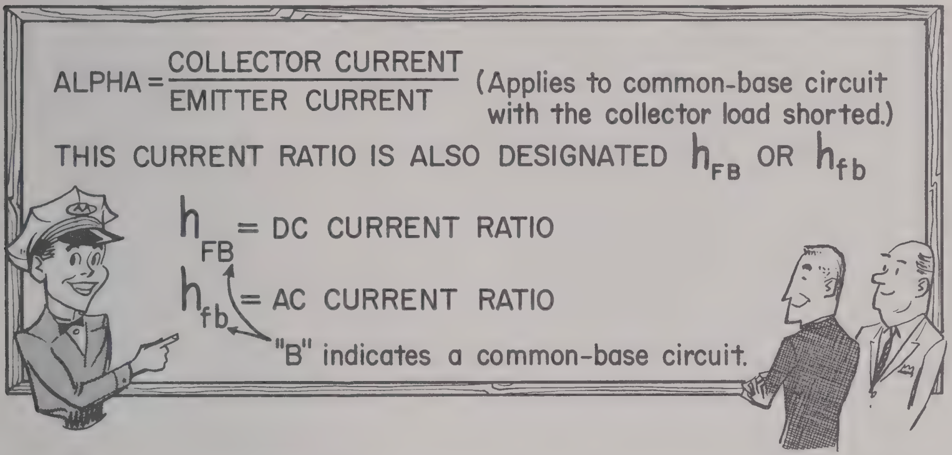
Let's take the values of figures 1 and 2 and see if these conversion formulas apply. From figure 1 we have an alpha of 0.98. Applying this value in formula (1) we have:

$$\beta = \frac{\alpha}{1 - \alpha} = \frac{.98}{1 - .98} = \frac{.98}{.02} = 49$$

Using this value of beta (49), we convert to alpha by using formula (2):

$$\alpha = \frac{\beta}{1 + \beta} = \frac{49}{1 + 49} = \frac{49}{50} = .98$$

From the above, we see that these formulas may be used to convert from a given value of alpha or beta to the other with relative ease.


ALPHA = $\frac{\text{COLLECTOR CURRENT}}{\text{EMITTER CURRENT}}$
(Applies to common-base circuit with the collector load shorted.)
THIS CURRENT RATIO IS ALSO DESIGNATED h_{FB} OR h_{fb}
h_{FB} = DC CURRENT RATIO
h_{fb} = AC CURRENT RATIO
"B" indicates a common-base circuit.

Alpha and "h_{FB}" or "h_{fb}" Ratings Refer to the Common-Base Circuit With the Collector Load Shorted.

Common-Collector Currents

The preceding discussions about transistor currents (including alpha and beta ratings) are concerned with common-emitter and common-base circuits. Nothing has been said so far about the currents of the common-collector circuit. This arrangement is seen in figure 3.

In the common-collector circuit, although the collector is common to both the input and the output, as far as the current gain is concerned we are interested in the base and emitter currents; they are the input and output currents, respectively. Thus, the current gain is the ratio of the emitter current to the base current. Using the values of figures 1 and 2 for figure 3, we have a ratio of 1 ma to 0.02 ma, a current gain of 50.

At first consideration, with a high current gain it appears that the gain realized in this common-collector circuit is the highest of all three circuits. On the contrary, there are other considerations which enter into the picture to cause the lowest power gain and a voltage loss for the common-collector arrangement. The circuit has some characteristics, however, which makes it very useful and advantageous in certain specific applications. We shall study the circuit in greater detail later.

In foregoing discussions we have mentioned the resistances or impedances of the various transistor circuits and the fact that transistor amplifier gain depends upon a higher impedance in the output than present at the input. We are now ready to look further into this matter, beginning with the input.

Input Resistance-Impedance

We often hear the term "input resistance" used in connection with both vacuum-tube and transistor amplifiers. While resistance normally refers to the opposition offered to DC current, it is used more freely here to indicate the impedance or opposition to AC. Strictly speaking, however, resistance should be reserved for DC opposition and in the following discussion we shall follow this idea and reserve the term impedance (Z) for the AC opposition.

"Input Impedance," then, is the opposition to AC current encountered by a signal applied to the input of some device. This impedance is not always constant, but varies with frequency and other factors. As an example of input impedance, inspect figure 4. Here an input signal is applied to a transistor amplifier, and the amplifier offers a certain amount of opposition (Z) to AC current.

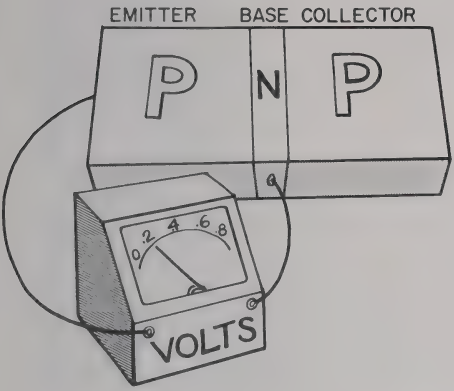
The amount of impedance may be determined if the input signal voltage (e_{in}) and the current (i_{in}) are known. This impedance may then be calculated by applying Ohm's Law for AC circuits, in which impedance (Z) is substituted for "R," the DC opposition. The formula now becomes: $Z = e_{in} \div i_{in}$. The small letters are used here to indicate signal current and voltage.

In figure 5 we see a more detailed circuit showing the input impedance of the transistor amplifier. This is a common-base arrangement, and for simplicity the biasing arrangement has been omitted.

There are two parallel paths for the applied signal--through emitter resistor RE and through the emitter-base section of the transistor. The resistance (and impedance) of the emitter resistor is usually considerably greater than the impedance of the transistor, so, being in parallel, it does not greatly change the net impedance. The total impedance in this instance is determined almost entirely by the transistor.

The emitter-base impedance for this particular circuit is usually in the vicinity of 200 ohms or less, meaning that the input impedance for the common-base circuit is very small. This low value of input impedance is different from the high input resistance we have become accustomed to for the vacuum tube, where the grid is biased to prevent grid current.

The above mentioned value of 200 ohms or less is typical for low-frequency applications where the reactances (opposition to AC current) of the various circuit capacitances are sufficiently high that they do not affect the impedance. At high frequencies, however, these reactances must also be taken into consideration, for they further decrease the input impedance. Transistor circuit behavior, such as feedback from the



The Average Forward Bias at the Emitter-Base Terminals of a Transistor is About 0.2 Volt.

output to the input, also alters the effective impedance at the input, and again the effect varies with the frequency and the circuit arrangement.

Output Impedance

AC currents in the complete output circuit of an amplifier encounter two separate impedances. Represented in figure 6, these are: (1) the impedance internal to the device (the transistor in this case) and (2) the external or "load" impedance. If we are to avoid confusion, it is important to differentiate between these two impedances. Thus, we will refer to the internal impedance as the "output" impedance, and to the external impedance as the "load."

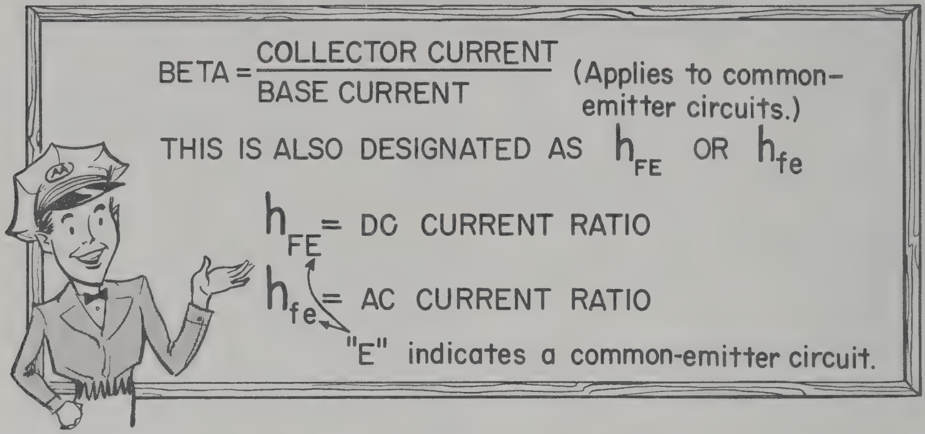
The internal impedance cannot be isolated to just one separate factor internal to the transistor. Instead, it depends upon many factors such as the ratio of the collector current to the collector voltage, the internal feedback of the unit, and the current gain of the device.

Similarly, the load impedance cannot be limited to the resistor, coil, or tuned circuit which may be in the collector DC current path. Instead, anything connected to the output of the amplifier, such as the input circuit of the following stage, becomes part of the output circuit and alters the load impedance.

In figure 6 the amplifier terminates into a "load." For the final stage of a receiver, this load is the speaker. In many instances the load is the input circuit to another amplifier. Regardless of the nature of this load, its presence must be taken into consideration in determining the load impedance of the amplifier.

Figure 7 shows a typical output arrangement of a transistor amplifier which terminates into the input of another amplifier. The collector or output circuit has three paths for the signal: (1) collector resistor RC, (2) emitter resistor RE, and (3) the emitter-base section of the next stage. (The coupling capacitor is chosen to have negligible opposition to currents at the signal frequency.)

The net impedance offered by those three parallel paths is the load impedance of the amplifier


$\text{BETA} = \frac{\text{COLLECTOR CURRENT}}{\text{BASE CURRENT}}$
(Applies to common-emitter circuits.)
THIS IS ALSO DESIGNATED AS h_{FE} OR h_{fe}
h_{FE} = DC CURRENT RATIO
h_{fe} = AC CURRENT RATIO
"E" indicates a common-emitter circuit.

Beta and "h_{FB}" or "h_{fb}" Ratings are Determined with the Collector Load Shorted.

stage. For the transistor amplifier, it is usual practice to match the load impedance to the output impedance, for this produces maximum gain. For the common-base arrangement we have been considering, 50,000 to 100,000 ohms is a typical output impedance.

Impedance Gain

The fact that the transistor usually presents a low input impedance and a high output impedance accounts for its consideration as a TRANSfer-resISTOR. If it were not for this impedance transformation, the transistor might not be desirable as an amplifier.

For the common-base circuit, a small signal current through a low impedance is transferred into a similar signal current at the output, but here the current is established in a high impedance. The "gain" of this circuit is determined almost entirely by the impedance ratio or gain.

Before discussing voltage amplification and power gain in transistor circuits, however, we shall look at the typical impedances of the various circuits. At this point in our discussion we will consider only the typical impedances for low-frequency applications, such as those used for audio amplification.

Common-Base Circuit Impedances

The common-base circuit--see figure 8--offers the lowest input impedance and the highest output impedance of all the various transistor configurations. We have already discussed typical values for the common base circuit in the preceding paragraphs, finding that the input impedance is likely to be below 200 ohms. In fact, it would not be unusual for this impedance to be below 50 ohms at higher frequencies.

The output impedance often may be as high as 100,000 ohms or more, but it is not always possible to match this high output impedance in the load. Merely to insert a high impedance component in the collector circuit is not enough. The impedance of the remainder of the output circuit (the input to the next stage, etc.) must be taken into consideration. A further discussion of this involves coupling methods and devices and more will be said about these things a little later in this lesson.

The ratio of the output impedance to the input impedance is the highest for the common-base circuit. This means that the impedance gain of the circuit is the highest of the three transistor arrangements. Impedance gains as large as 1000 or more are common.

Common-Emitter Circuit Impedances

The input impedance of the common-emitter circuit is not as low as that of the common-base circuit and its output impedance is not as high as that of the common-base arrangement. As indicated in figure 9, a typical input impedance ranges from 1000 to 5000 ohms and the output impedance is likely to be somewhere between 10K and 50K ohms.

The impedance ratio or gain of the common-emitter circuit is usually around 10, which means that this circuit, which has the highest gain of all the various circuits, does not depend upon the impedance gain alone for its ability to amplify. We may recall from our preceding discussion that a current gain is also realized by this circuit.

Common-Collector Circuit Impedances

The impedance condition for the common-collector circuit (figure 10) is different from that of the common-base and common-emitter circuits--there is no impedance gain from the input to the output. Instead, the input impedance is higher than the output impedance.

It is not practical to suggest typical impedance values or ranges of the common collector circuit, for the input impedance is determined to a large extent by the load impedance. We can, however, express a relationship between the input and output impedance: depending upon the current gain of the transistor, the input impedance will usually be somewhere between 20 times to 100 times the output impedance. Thus for an output impedance of 1000 ohms, the input impedance will probably be between 20K and 100K ohms. Again, we are speaking of low-frequency applications.

While the common-collector circuit has an impedance loss from its input to its output, it has a relatively high value of current gain which compensates to a large extent for the impedance loss and makes the circuit very desirable and practical for certain applications, such as impedance transformation.

Amplification and Gain--Common Base Circuit

We have already spoken of the current gain within the common-base circuit--the gain being h_{FB}, the ratio of the collector current to the emitter current. In addition, we found that this circuit possesses a high impedance gain. These two factors account for the voltage amplification and power gain of the common-base transistor amplifier.

The amount of voltage amplification is determined by the ratio of the output signal voltage to the input signal voltage and, by applying Ohm's Law to both the input and output circuits, we can readily determine these voltages from the currents and impedances.

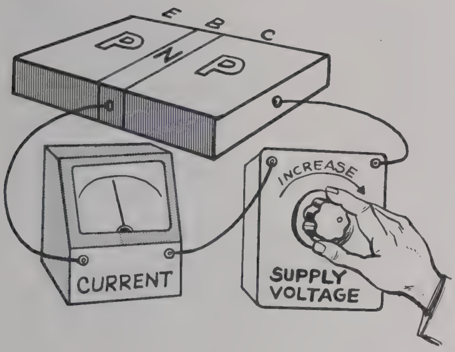
Referring to figure 11, with an input signal current of 0.1 ma and an input impedance of 50 ohms, the input voltage is 0.005 volt; the output voltage is calculated to be 4.9 volts (using the output current and impedance). The ratio of the output voltage to the input voltage is 980. This value corresponds closely to the impedance gain of 1000.

If the current gain (alpha) were unity, the voltage amplification would be equal to the impedance ratio. The same value of voltage amplification (980) results if we use formula (2) in Figure 11, and multiply the h_{FB} by the impedance gain.

The power gain of the stage is the true indication of the worth of the circuit as an amplifier, and the power gain is the ratio of the output signal power to the input signal power. We can determine the power gain of the common-base circuit of figure 11 from the values that are already known--the procedure is given in figure 12. In fact, once the three values of voltage, current and impedance are known, any of the formulas for determining power may be used.

From figure 12 we find that the power gain is 960, indicating that the output power is 960 times greater than the power at the input. This value is also nearly the same as the impedance gain; as the value of h_{FB} approaches unity the power gain approximates the impedance gain. In addition to finding the power gain from known values of output and input power, we may determine the power gain from alpha and the impedance gain--the formula is given in figure 12. (This assumes the load impedance is small compared to the output impedance.)

The gain of the stage as specified in decibels is conveniently determined from the power gain. A power gain of 1000 is a 30-db



Once Collector Current has been Established in the Transistor, Increasing the Collector Voltage has Little Effect Upon the Collector Current.

gain, so a gain of 960 is slightly less than 30 db. The actual calculation (using "logs" or a chart) establishes the gain at 29.8 db.

The db gain of the stage is determined from the power gain rather than from the voltage ratio or amplification. The only time it is permissible to determine the db rating from the voltage is when the input and output voltages appear across the same value of impedance. This is not true of the transistor circuits of figures 11 or 12.

Amplification and Gain--Common Emitter Circuit

Figure 13 shows the basic arrangement of a common-emitter amplifier, and we have assumed the same current values as for figures 11 and 12. The impedance gain of 10 is typical for this configuration.

The voltage amplification is determined in the same manner as was done for the common-base circuit. Two methods of determining the amplification are given in figure 13: (1) the ratio of the output and input voltages, and (2) the current gain multiplied by the impedance gain. The results (490) are the same in both calculations.

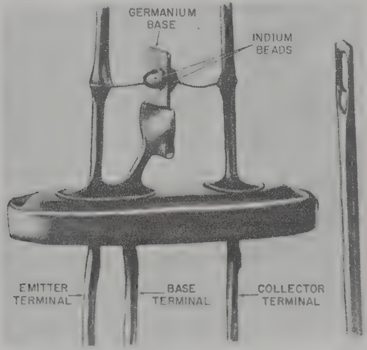
The power gain of the common-emitter circuit is illustrated in figure 14. Calculations for the individual powers of the input and output circuits are impractical in that they involve very small decimal values. It is much more convenient to determine the power gain from the known current and impedance ratios, and the answer will be the same. As shown, the power gain is approximately 24,000, and this is considerably greater than the power gain of the common-base circuit. This is a 44 db gain, a value possible to realize in practical circuitry.

Since the power gain of a circuit is the true indication of the amplifier's worth, the common emitter circuit is the most often used. Only where their characteristics are more suitable for the needs of a particular stage is it advantageous to use other circuits.

Amplification and Gain – Common Collector Circuit

We have already seen that the common-collector circuit is similar in its operation and characteristics to the cathode-follower vacuum-tube circuit. Continuing with this comparison, the common collector would be called an "emitter follower." There is no voltage amplification and the power gain of the circuit is the lowest of all three transistor arrangements. The current gain of the circuit is the highest, being the ratio of the emitter (output) current to the base (input) current. The current gain is slightly higher than beta (h_{fe}).

Referring to the common-collector circuit of figure 15, with an emitter current of 0.1 ma and a base current of .002 ma, the current gain is 50. With this high value of current gain we might anticipate a large voltage amplification and power gain, but there is an impedance loss rather than a gain, with the result that there is no voltage amplification and little power gain--the stage is not very desirable as an amplifier. Instead, this circuit is usually employed as an impedance-matching device.



Here We See the Actual Construction of a Low-Power, Low-Frequency Transistor. The Actual Size May be Judged by the Size of the Needle at the Right.

The output impedance is determined to a great extent by the source impedance and the current gain. In practical circuitry we find that the input impedance is between 20 and 100 times the load impedance.

The voltage ratio of the output to the input (the amplification) is found by the now familiar method of multiplying the current gain by the impedance gain. Regardless of how large the current gain may be, the impedance ratio always changes accordingly and the amplification is always less than 1.

The power gain is also determined from the current and impedance ratios. In the figure we find that a power gain of 45 has been realized, and this is relatively low compared to the power gains of the common-base and common-emitter circuits. If transistors having higher current gains are used, the power gain will also be higher. Typical values of power gain range from 20 to 200 (13 to 23 db).[1]

Coupling Transistor Stages

Whether we are concerned with vacuum tube or transistor amplifiers, the coupling between stages or at the input and output presents a problem. The procedures and

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1. See Basic Theory and Application of Transistors (TM11-690) pages 52-84 and pages 102-111.

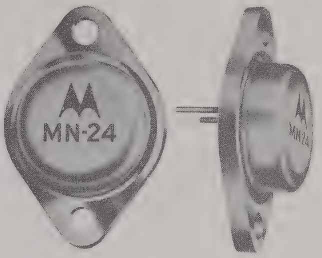
considerations associated with vacuum-tube amplifiers also apply to transistor circuits. Compared to vacuum tube circuitry, however, transistor input and output impedances usually have a greater variation and hence require closer attention.

Among the more perplexing problems encountered in transistor circuitry which are not as noticeable with vacuum tubes are the interaction between the input and output circuits and the effect of the impedance of one circuit upon the impedance of the other. As an example, as the output load impedance increases the input impedance decreases and vice versa. This effect is hardly noticeable with vacuum tubes, for changes of plate load impedance do not notably change the effective grid impedance.

The most common methods of coupling transistor stages are transformer coupling and RC coupling. We shall discuss each of these separately, beginning with transformer coupling.

Transformer Coupling

Maximum gain within one stage or several stages of amplification is made possible by the impedance-matching transformer. By adjusting the turns ratio, the output impedance of one stage is matched to the input impedance of the next (or to some other load). Unless a match is effected, the over-all gain will be sacrificed.



This Power Transistor is Considerably Larger Than the Low-Power Transistors Discussed in this Lesson.

Transformers, unfortunately, have several disadvantages. They are heavy and space consuming, which is not conducive to their use in light, compact equipment. In addition, transformers which are small enough to be practical for such equipment are expensive. Transformers are also subject to hum pickup and core saturation.

Transformers for transistor circuits are designed in much the same manner as those for vacuum-tube circuits. The turns ratio is determined by the desired impedances of the primary and secondary, and each winding depends upon the power requirements and the desired frequency response.

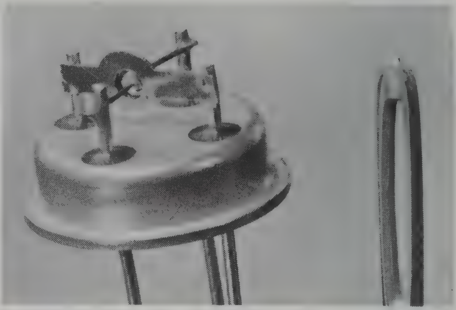
Figure 16 shows a simple circuit of a common-emitter amplifier stage having transformer coupling at both its input and its output. The biasing method for this circuit is interesting--one battery is used for both emitter and collector bias. The positive side of the battery is grounded and is thus connected directly to the grounded emitter.

A voltage divider composed of R1 and R2 provides the desired forward emitter bias, with the voltage across R2 being the voltage at the emitter and base. The collector is connected to the negative side of the battery through a transformer winding and, with negligible DC voltage drop across the windings, the voltage across R1 is the reverse collector bias.

The input transformer (figure 16) serves as an impedance-matching device between a high-impedance source (connected to the primary of the transformer) and a low-impedance load (the input circuit of the amplifier). Because of this impedance match, maximum signal power reaches the input circuit.

The fact that the primary has a greater number of turns than the secondary means that the low-impedance load of the secondary actually looks like a high impedance to the primary. (The reflected impedance to the primary is determined by the square of the turns ratio. A transformer having a 5 to 1 turns ratio has an impedance ratio of 25 to 1, and a 1000 ohm load at the secondary looks like a 25000 ohm load in the primary.)

It may appear that the lower secondary voltage (due to the step-down ratio of the transformer) is less desirable than a higher voltage such as that of the primary. This is not the case. We must remember that the transistor is a current operated device, and the fewer turns in the secondary is capable of delivering higher currents to the low-impedance input circuit--assuming that the impedances are matched--than can be delivered by a higher voltage secondary. By matching the impedances, then, maximum power is available at the input circuit of the amplifier. The signal currents in the base circuit--through the emitter-base junction--cause appreciable changes in collector current.



This Photo Shows the Typical Construction of Medium-Low Power Audio Transistors.

At the output of the stage we have the same problem encountered in the input--a high impedance is desirable for the collector circuit, but the load (the input of the following stage) is a low impedance. Again the impedance-matching transformer is the answer. The primary of the output transformer has a large number of turns and a high impedance; the secondary has fewer turns and a low impedance.

The turns ratio is controlled so that the load impedance at the secondary reflects the desired impedance into the collector circuit. Thus, the effective load in the collector circuit depends directly upon the impedance of the load connected to the secondary.

The circuit of figure 16 is by no means the final arrangement which might be found in equipment. There are other factors such as feedback and neutralization which often require additional circuitry, and, in most transistor circuits, some provision is made to minimize the effects of temperature changes within the transistor. These things will be discussed in detail as we progress with our study of transistor circuits and operation. Right now we are ready to continue with coupling methods.

RC Coupling

While transformer coupling is advantageous to use in audio circuits where large signal currents and powers are present, or where tuned circuits are necessary, the RC coupled amplifier finds many applications where compactness, light weight and economy are the important factors. R-C coupling is particularly adaptable to low-level audio stages, where the hum pickup by transformers is very detrimental.

Figure 17 gives the basic circuit components of RC coupling between stages. The coupling components are the collector resistor (RC), the coupling capacitor (CC) and the base resistor (R2). These components correspond to the plate load resistor, the coupling capacitor and the grid resistor, respectively, in RC-coupled vacuum-tube stages.

Resistor R1 forms a voltage divider with R2 to provide forward bias to the emitter junction of transistor Q2. The output voltage of the first stage is coupled to the base of the second stage by the coupling capacitor. The reactance (AC resistance) of this unit must be small compared with the impedance of the associated resistors, and with a low-impedance input to the second stage, the reactance of the capacitor will be extremely low--much lower than we are accustomed to find in vacuum tube-circuits. In fact, in order to provide a low reactance for this capacitor at low audio frequencies, it is necessary to use an electrolytic or tantalum type. Due to the low supply voltage, a unit having a low voltage rating will suffice.

Another difference between the coupling capacitor of figure 17 and that of the vacuum-tube circuit is in the tolerable leakage current. The slight leakage of electrolytics does not normally have any great effect upon the operation of transistor stages, although the same leakage in vacuum-tube circuits may produce a substantial change in the operation and damage some of the circuit components.

Unlike transformer coupling, RC coupling does not provide an impedance match between stages. The input of the second stage determines to a large extent the impedance presented to the output section of the preceding stage. As a result, the RC-coupled amplifier provides less power gain; their gain varies with the degree of matching between the desired impedance at the output of one stage and the input impedance of the next stage.

Figure 18 compares the gains that may be realized with two stages of RC coupling, using different configurations and various values of input and output impedances. The indicated gains are for transistors having the characteristics shown at the top of the figure. The configurations of the stages are abbreviated CB, CC and CE, referring to common base, common collector and common emitter, respectively.

The two columns at the left show source and load impedances. Stages in the upper group have the same input and output impedances; those in the middle group have input impedances which are lower than the output impedances; those in the last group have output impedances which are lower than the input impedance.

The importance of matching the transistor impedances can be seen by the gains for the two-common collector stages, (1) where the input is low and the output high, and (2) where the input is high and the output is low. With a 100-ohm source and 100K-ohm load, the (CC) gain is -24 db, indicating a considerable loss. A 100K-ohm source and a 100-ohm load, however, result in a gain of 33.5 db. The difference in gain is thus 57.5 db, a power ratio of nearly 1,000,000 to 1.

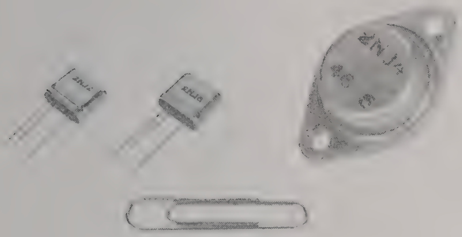
Although the double common-emitter arrangement yields maximum gain in most instances, there are certain conditions where some of the other configurations yield comparable results, often with a reduction of distortion.

Other Coupling Methods

In addition to transformer and RC coupling, we occasionally find impedance-coupled and direct-coupled stages. Let's discuss briefly each of these.

Impedance coupling is very similar to resistance coupling, the only difference is that one of the two resistors used for RC coupling is replaced by a coil or a tuned circuit. In figure 19A, we find a coil (1) in the collector circuit of Q1. This coil presents an impedance to AC currents at the signal frequency. The big difference between this and RC coupling is that the coil offers a high impedance to AC but at the same time its DC voltage drop is very small.

Direct coupling is shown in figure 20. Only one resistor, common to both the collector and base,



Here We See the Comparative Size of Low and High Power Transistors.

is required. The collector of Q1 is connected directly to the base of Q2, so these two points are at the same DC potential. The circuit has several distinct advantages. First, there are a minimum number of parts in the coupling circuit, resulting in savings of both space and money. Second, where the DC components of the signal must be preserved (or amplified) it is still present at the output of Q2. (One particular application is the DC restorer-amplifier circuit of TV receivers.)

There is one great disadvantage, however, which prevents greater use of direct coupling. All transistors have a certain amount of DC instability with changes of temperature. This problem is multiplied by successive stages of direct coupling, with the result that a large amount of feedback must be used to bring about satisfactory stability. This feedback limits the gain which may be realized in each stage.[2]

Summary

In this lesson we studied the various currents and impedances in the three transistor circuits, the common base, the common emitter and the common collector. We found that the amplification and gain provided by each circuit are dependent upon the current gain and the impedance gain, and comparisons were made for the three configurations--they are summarized in figure 21.

The low input impedance and the high output impedance of the common-base circuit give a high impedance gain, but the current gain (h_{FB}) is always less than unity. While the resulting voltage amplification is high, the power gain is only medium. In addition, we learned in a preceding lesson that the circuit does not produce a phase inversion (180° phase shift) of the input and output signal. This circuit is convenient to use between a very low impedance source and a high impedance load.

The common-emitter circuit has only a medium impedance gain, but this coupled with a high current gain (h_{FE}) produces a high voltage amplification and the highest power gain. There is a phase reversal of the input and output signal. This is the most popular circuit for transistor amplifiers.

The common-collector circuit has a higher input impedance than output impedance, resulting in a considerable impedance loss. Although the current gain is high, the voltage amplification is always less than unity and the power gain is the lowest of all three circuits. The output signal has the same phase as the signal input. This circuit is used primarily for impedance-matching purposes, from a high impedance to a low impedance loss.

---

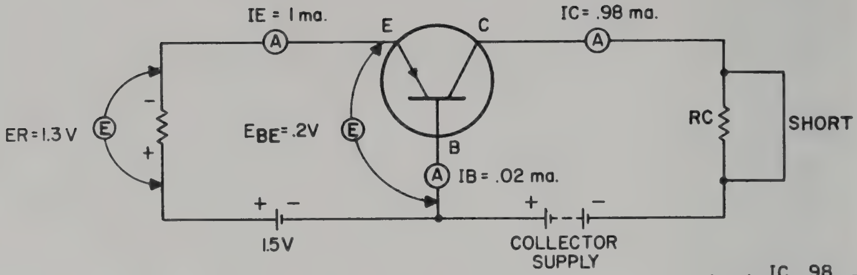
[2] See TM11-690, pages 118-124.

In this lesson we also learn about the transformer and RC coupling. Transformer coupling is used where impedance matching is important and the signal is large. Tuned transformer coupling is normally found in IF and RF circuits. RC has the advantage of being compact and lightweight; it is used extensively in low-frequency, low-level stages.

STUDENT NOTES

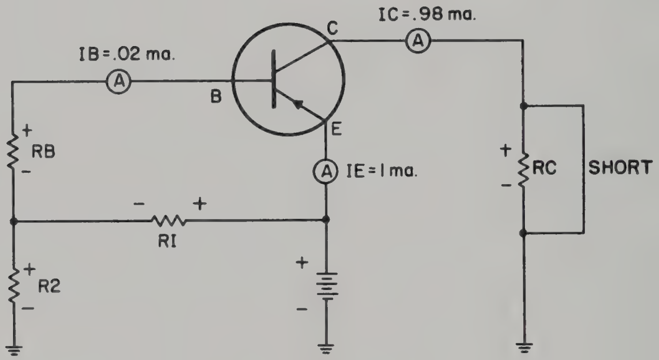
STUDENT NOTES

STUDENT NOTES



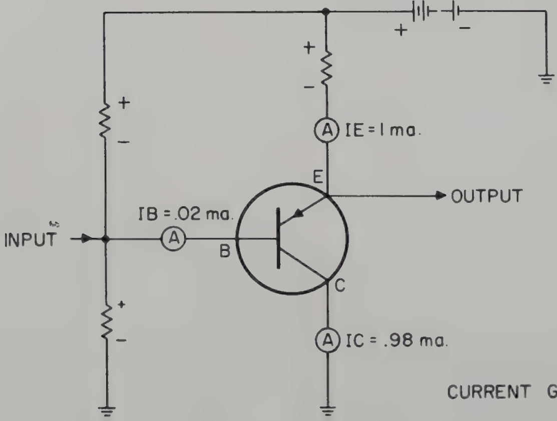
$\text{ALPHA } (h_{FB}) = \frac{IC}{IE} = \frac{.98}{1} = .98$

COMMON BASE AMPLIFIER
FIGURE I



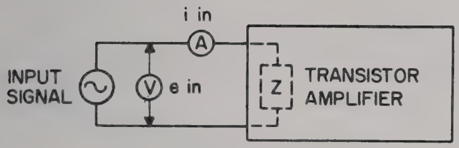
$\text{BETA } (h_{FE}) = \frac{IC}{IB} = \frac{.98}{.02} = 49$

COMMON EMITTER AMPLIFIER
FIGURE 2



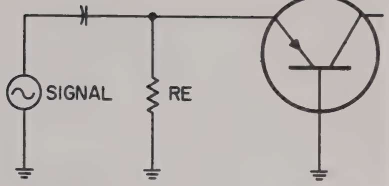
$\text{CURRENT GAIN} = \frac{IE}{IB}$

COMMON COLLECTOR
FIGURE 3

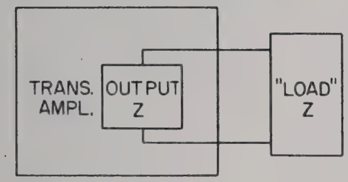


$$Z\ \text{in (IMPEDANCE)} = \frac{e\ \text{in}}{i\ \text{in}}$$

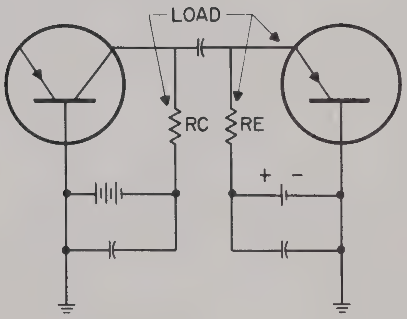
INPUT IMPEDANCE
FIGURE 4



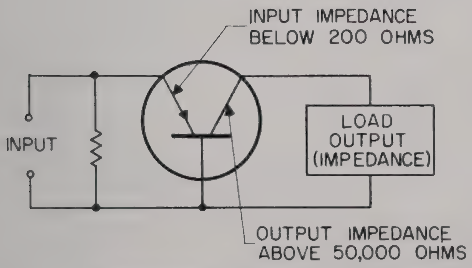
INPUT IMPEDANCE
FIGURE 5



OUTPUT IMPEDANCE
FIGURE 6

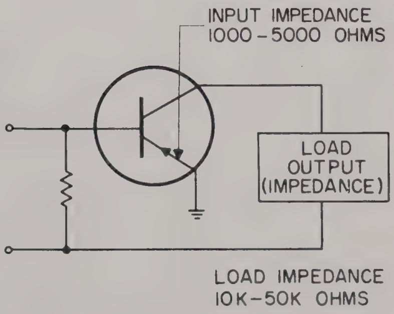


OUTPUT LOAD (IMPEDANCE)
FIGURE 7


INPUT IMPEDANCE BELOW 200 OHMS
INPUT
LOAD OUTPUT (IMPEDANCE)
OUTPUT IMPEDANCE ABOVE 50,000 OHMS

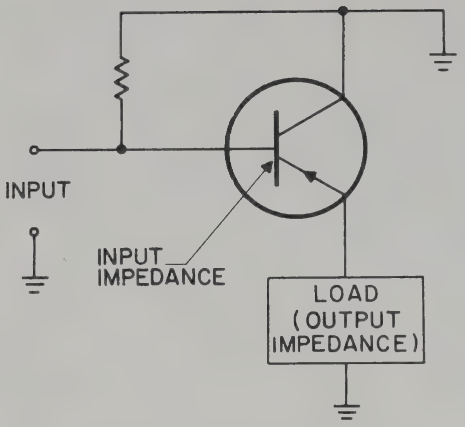
IMPEDANCES GAIN: 1000 OR MORE

"COMMON BASE" IMPEDANCES
FIGURE 8



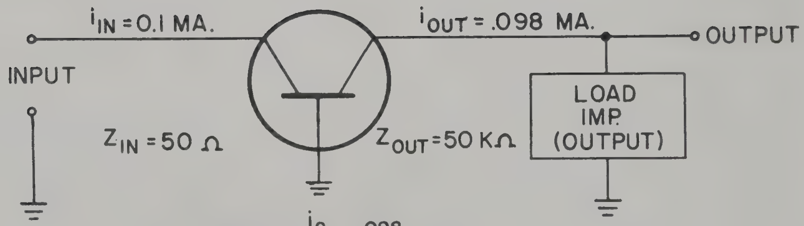
IMPEDANCE GAIN: 10

"COMMON EMITTER" IMPEDANCES
FIGURE 9



INPUT IMPEDANCE 20-100 TIMES THE OUTPUT IMPEDANCE
NO IMPEDANCE GAIN

"COMMON COLLECTOR" IMPEDANCES
FIGURE 10



$$\text{ALPHA} = \frac{i_c}{i_e} = \frac{.098}{.1} = .98$$

$$e_{IN} = i_{IN} \times Z_{IN} = .0001 \times 50 = .005 \text{ VOLT}$$

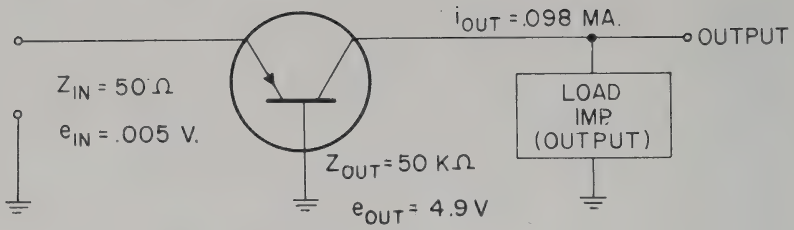
$$e_{OUT} = i_{OUT} \times Z_{OUT} = .000098 \times 50{,}000 = 4.9 \text{ VOLTS}$$

1. VOLTAGE AMPLIFICATION = $\frac{e_{OUT}}{e_{IN}} = \frac{4.9}{.0005} = 980$

2. VOLTAGE AMPLIFICATION = ALPHA x Z GAIN
= .98 x 1000 = 980

VOLTAGE AMPLIFICATION
COMMON BASE CIRCUIT

FIGURE 11



$$hFB = \frac{i_{OUT}}{i_{IN}} = \frac{.098}{.01} = .98$$

1. POWER GAIN $= \frac{P_{OUT}}{P_{IN}} = \frac{I^2 Z}{I^2 Z}$

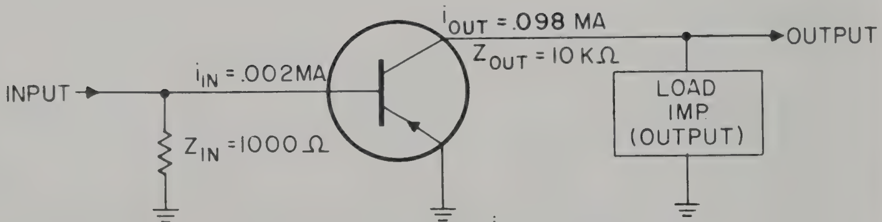
$$= \frac{(.000098)^2 \times 50{,}000}{(.0001)^2 \times 50}$$

$$= 960$$

2. POWER GAIN $= hFB^2 \times Z$ GAIN

$$= .98^2 \times 1000$$
$$= .96 \times 1000$$
$$= 960$$

POWER GAIN
COMMON BASE CIRCUIT
FIGURE 12



$$\text{BETA (B)} = \frac{i_{OUT}}{i_{IN}} = \frac{.098}{.002} = 49$$

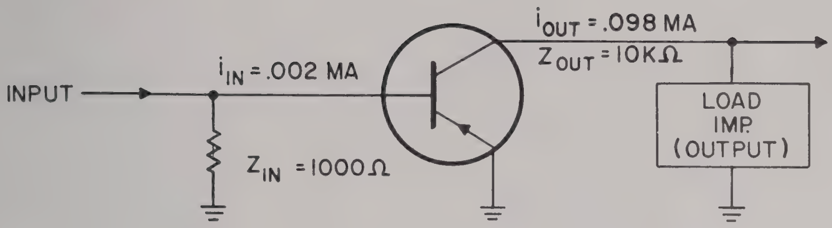
$e_{IN} = i_{IN} \times Z_{IN}$
$= .000002 \times 1000$
$= .002$ VOLT

$e_{OUT} = i_{OUT} \times Z_{OUT}$
$= .000098 \times 10{,}000$
$= .98$ VOLT

1. VOLTAGE AMPLIFICATION $= \frac{.98}{.002} = 490$

2. VOLTAGE AMPLIFICATION $= B \times Z$ GAIN
$= 49 \times 10 = 490$

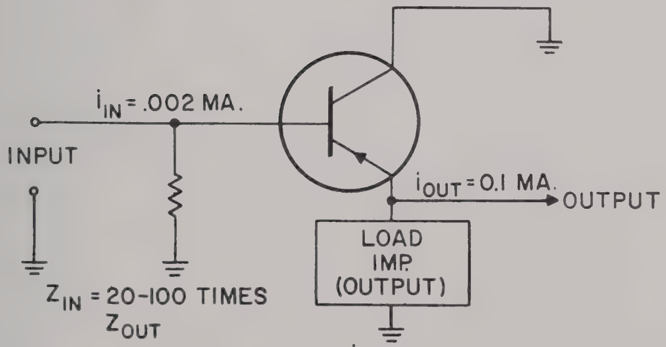
VOLTAGE AMPLIFICATION
COMMON EMITTER AMPLIFIER
FIGURE 13



$$\text{BETA (B)} = \frac{i_{OUT}}{i_{IN}} = \frac{.098}{.002} = 49 \qquad \text{Z GAIN} = \frac{Z_{OUT}}{Z_{IN}} = \frac{10\text{ K}}{1\text{ K}} = 10$$

$$\begin{aligned}\text{POWER GAIN} &= (B)^2 \times \text{Z GAIN}\\ &= (49)^2 \times 10\\ &= 24000\\ &= 44\text{ db.}\end{aligned}$$

POWER GAIN
COMMON EMITTER AMPLIFIER
FIGURE 14



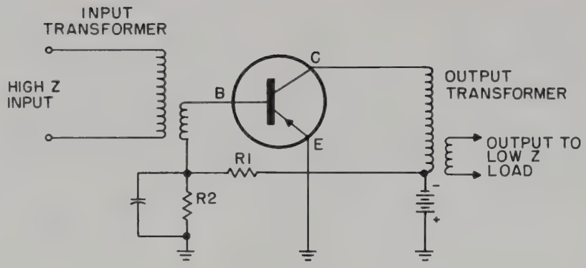
$$\text{CURRENT GAIN} = \frac{i_{OUT}}{i_{IN}} = \frac{.1}{.002} = 50$$

Z GAIN IS THEN LESS THAN $\frac{1}{50}$

$$\begin{aligned}\text{VOLTAGE AMPLIFICATION} &= \text{CURRENT GAIN} \times \text{Z GAIN}\\ &= 50 \times \frac{1}{55}\\ &= .9\end{aligned}$$

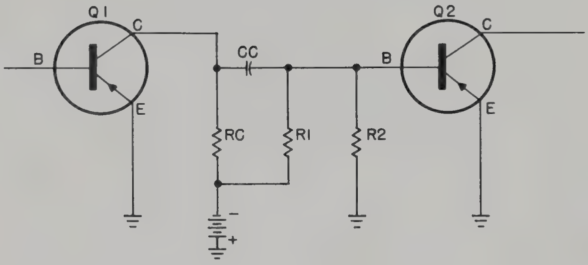
$$\begin{aligned}\text{POWER GAIN} &= (\text{CURRENT GAIN})^2 \times \text{Z GAIN}\\ &= (50)^2 \times \frac{1}{55}\\ &= 45\ (16.5\text{ db.})\end{aligned}$$

AMPLIFICATION AND GAIN
COMMON COLLECTOR CIRCUIT
FIGURE 15



TRANSFORMER COUPLING

FIGURE 16



"RC" COUPLING

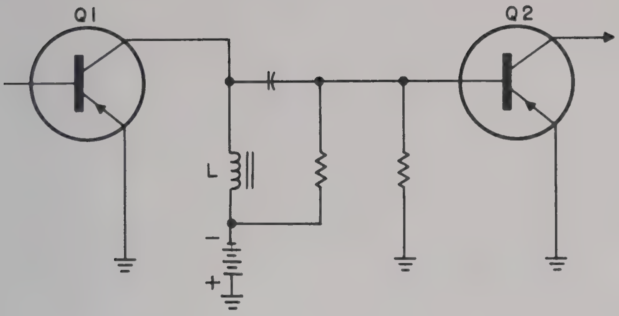
FIGURE 17

TRANSDUCER GAIN OF CASCADED PAIRS OF TRANSISTOR AMPLIFIERS

$r_e = 25\Omega$ $r_b = 600\Omega$ $r_c = 2 \times 10^6\Omega$ $\alpha = 0.985$

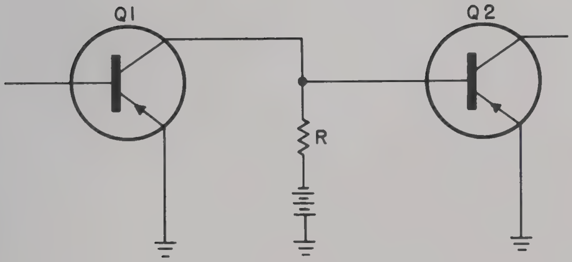
1st STAGE		CE	CB	CC	CE	CB	CE	CC	CC	CB
2nd STAGE		CE	CB	CC	CB	CE	CC	CE	CB	CC
SOURCE	LOAD	POWER GAIN IN DECIBELS								
100	100	51.6	3.2	3.5	14.8	39.7	51.4	15.1	9.0	39.6
1000	1000	71.6	5.6	5.8	32.0	41.9	63.0	35.1	27.5	41.9
10K	10K	74.5	6.0	6.0	40.5	39.8	51.2	54.4	39.0	37.8
100K	100K	66.0	5.4	6.0	42.1	29.5	41.1	62.4	41.8	24.6
100	1000	61.6	13.2	-4.2	24.8	49.7	58.3	25.1	19.1	48.5
100	10K	68.8	23.2	-13.9	32.0	57.0	56.9	35.1	28.7	49.9
100	100K	68.6	32.8	-24.0	44.8	56.9	41.1	41.6	35.8	42.8
100K	100	48.6	-24.0	33.5	12.1	12.2	48.7	40.8	12.0	12.4
10K	100	57.0	-14.0	23.5	20.5	22.2	57.1	34.6	19.1	22.4
1000	100	58.5	-5.5	13.5	22.0	31.9	58.6	25.1	17.5	32.1

FIGURE 18



IMPEDANCE COUPLING

FIGURE 19



DIRECT COUPLING

FIGURE 20

CIRCUIT	CURRENT GAIN	INPUT Z	OUTPUT Z	Z GAIN	VOLTAGE AMPL.	POWER AMPL.	180° PHASE SHIFT
COMMON BASE	LESS THAN 1 (ALPHA)	LOW	HIGH	HIGH	HIGH	MEDIUM	NO
COMMON EMITTER	HIGH (BETA)	MEDIUM LOW	MEDIUM HIGH	MEDIUM	HIGH	HIGH	YES
COMMON COLLECTOR	HIGH	HIGH	LOW	LOSS	NONE	LOW	NO

FIGURE 21

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Name ______________________________ Student No. ______

Street ____________________ Zone ____ Date ______

City ________________ State ________ Grade ______

EXAMINATION, LESSON SA-4

1. For transistor amplifiers, which current is the largest?
   Emitter current______. Base current______. Collector current______.

   Which current is the smallest?
   Emitter current______. Base current______. Collector current______.

2. In order to establish conduction in a transistor, it is essential to (forward) (reverse) bias the emitter junction, and (forward) (reverse) bias the collector junction.

3. A typical value of emitter-base voltage is:
   A. 2.0 volt______ B. 15 volts______ C. 1.5 volts______ D. 0.2 volt______

4. For the circuit of figure A, which of the following cause considerable change in the collector current? (Choose two answers)
   A. An increase in the E1 battery voltage. ______
   B. An increase in the E2 battery voltage. ______
   C. An increase in the resistance of R1. ______
   D. An increase in the resistance of R2. ______

5. Figure B shows a PNP transistor in a common-base arrangement. For the indicated values, the alpha (α) is:
   A. 0.25______ B. 0.40______ C. 0.75______ D. 4.0______ E. 0.8______ F. 0.2______

6. For figure B, the beta (β) is:
   A. 0.25______ B. 4.0______ C. 5.0______ D. 0.75______ E. 0.8______ F. 2.0______

7. The term "input impedance" refers to the opposition offered to AC current by the input circuit of a device.
   TRUE______. FALSE______.

8. The "output impedance" and "load impedance" are separate factors in a transistor amplifier. TRUE______. FALSE______.

9. Indicate the true statements about output impedance and load impedance in amplifiers.
   A. They are generally equal to the input impedance of the stage. ______
   B. Together, they represent the total impedance of the output circuit. ______
   C. They should be matched for maximum power gain. ______

10. Match the following:
    A. Common-base amplifier ________ Medium-low input impedance and medium high output impedance.
    B. Common-emitter amplifier ________ Low input impedance and high output impedance.
    C. Common-collector amplifier ________ Input impedance greater than output impedance.

FIGURE A

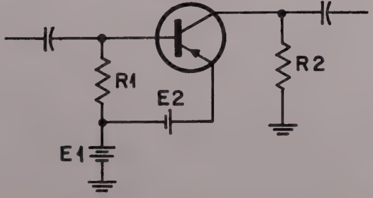
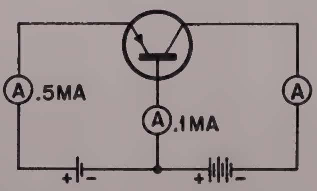


FIGURE B



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LESSON SA-5
TRANSISTORS

Transistor Bias: DC Circuitry

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A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON SA-5
TRANSISTORS

Transistor Bias: DC Circuitry

—one of a series of lessons on two-way FM communications—

MOTOROLA **TRAINING INSTITUTE**
4501 W. AUGUSTA BLVD., CHICAGO 51, ILLINOIS
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PREFACE

This is one lesson of a complete Motorola Home-Study Course which presents to the Service Technician both the principles of operation and the maintenance of two-way FM radio systems. The program covers mobile, portable and base station equipment, including the latest transistorized units.

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TRANSISTOR BIAS - DC STABILITY

LESSON SA-5

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NOTICE

Diagrams and figures referenced in text are "fold-outs" in back of each lesson, for use while studying. The Examinations are also there.

By using portable two-way radiophones, inventories and parts checking can be accomplished very efficiently. Waste motions and trips are cut to a minimum.

TRANSISTOR BIAS - DC STABILITY

Lesson SA-5

Introduction

In this lesson we shall discuss the various methods of providing bias for the three transistor circuits, the common emitter, the common base and the common collector. We shall also see the methods of stabilizing transistor operation against variations of temperature; unless some means of limiting the effects of heat is introduced, transistor operation may change drastically with temperature.

Common-Emitter Bias Circuits

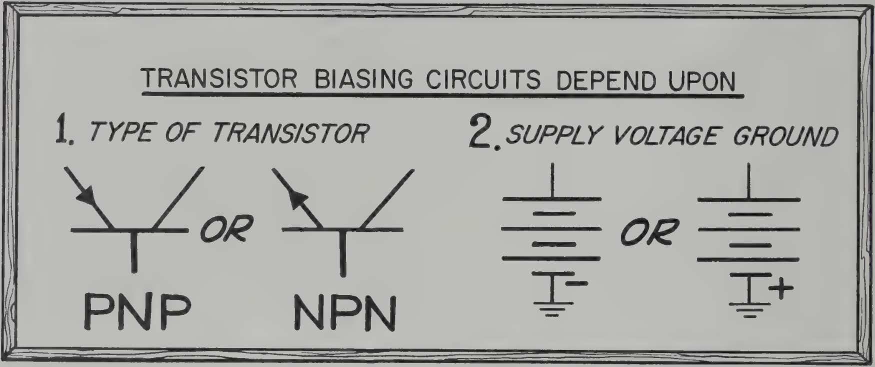
The final bias arrangement of any particular amplifier depends upon (1) the type of transistor--whether it is a PNP or an NPN transistor, and (2) whether the supply voltage to the stage has its positive or its negative terminal grounded.

Figure 1 shows a biasing circuit for a PNP-type transistor used as a common-emitter amplifier. The supply voltage has its positive terminal grounded. This means that the grounded emitter is the most positive point in the circuit. All other circuit terminals will be negative (less positive) by comparison.

Forward emitter bias is established between the emitter and base by means of voltage divider R1 and R2. The polarities of the voltages across these resistors are as marked. The voltage across R2 is the forward biasing voltage, for it is the voltage between the emitter and base. For low-power transistors of the type we have been discussing, 0.2 volt is a typical bias value.

Reverse bias between the collector and base of the PNP transistor is established by making the collector negative with respect to the base. Although both elements are negative to ground, the base is only a few tenths of a volt negative while the collector is several volts negative. (The collector-to-ground voltage is the difference between the supply voltage and the voltage drop across the collector resistor.) For typical supply voltages ranging from 6 to 12 volts, the collector will usually be between 3 and 10 volts negative to the base.

The value of the collector resistor is determined by both the required load impedance and the tolerable DC voltage drop. In many instances the collector load is a tuned circuit or a coil, in



The Biasing Arrangement of the Transistor Circuit Varies With (1) the Common or Grounded Terminal of the Supply and (2) the Type of Transistor.

which case the impedance may be made equal to the output impedance of the stage. At the same time, the DC drop across the coil is small and the collector is more negative than it would be if a resistor were used as the collector load.

Figure 2 shows a variation which might be made in the biasing circuit to accommodate a power supply which has its negative terminal grounded. The negative terminal is now the reference and all other points are considered with respect to ground -- they are so many volts positive.

Voltage divider R1 and R2 again provides the desired emitter-base bias voltage, only now the emitter-base voltage is the difference in the voltages of R1 and RB. The voltages across these resistors are opposing as far as the emitter-base voltage is concerned; the voltage across R1 is normally larger than that across RB, however, with the result that the emitter junction is forward biased.

In figure 1 the emitter is grounded, but in most circuits this is not standard practice. Instead, a resistor is connected between the emitter and ground -- see figure 3. A voltage drop is developed across the emitter resistor as a result of emitter current through it. This voltage drop has a polarity which opposes the bias voltage across R2, and the net emitter-base voltage is the difference in these voltages.

The voltage across R2 is greater than that of RE and the emitter junction is forward biased. The emitter resistor (RE) is usually bypassed. We will see the need for this resistor and its bypass later.

Figure 4 shows another biasing method for a common-emitter circuit when the supply voltage has its positive terminal grounded. The circuit is similar to that of figure 1, only in figure 4 there is no voltage divider in the base biasing circuit.

The emitter is connected to the positive side of the supply through emitter resistor RE. The collector is connected to the negative terminal of the supply through collector resistor RC; the collector-ground voltage is equal to the supply voltage less the amount of voltage drop across the resistor (caused by collector current through the resistor). As a result of this circuit arrangement and its voltages, the base is negative with respect to the emitter, but it is positive as far as the collector is concerned.

In figure 4 the voltage drop across the base resistor is determined by the base current through it. In figure 1, however, the voltage of the corresponding resistor, R1, is due mainly to the resistor being a part of the voltage divider, and the resistor has a low resistance compared to RB of figure 4. In figure 4, the only current through the resistor is the small base current and a higher resistance is needed to produce the required voltage drop.

The voltage across emitter resistor RE again has a polarity which opposes the forward bias. Later we shall see how this resistor stabilizes the operation of the stage for temperature changes. At this time we are interested only in its effect upon the initial bias.

Another bias method for the common-emitter circuit and a supply voltage with a positive ground is given in figure 5. The emitter is connected directly to ground and is the most positive point of the circuit. The collector load resistor (RC) connects to the negative side of the battery and the voltage drop across the resistor makes the collector less negative with respect to ground.

The base is connected to the collector through resistor R1, and the voltage drop across R1, due to base current through it, has the indicated polarity. This makes the collector negative to the base and the collector is reverse biased. The emitter is positive to the base, however, so that the emitter is forward biased.

A resistor is sometimes placed between the base and ground as shown in the figure. Where this occurs, the three resistors form a voltage divider between the negative terminal of the battery and ground. Although this additional resistor does not change the polarity of the voltages, different resistance values are required in order to provide the same voltages.

Common-Base Bias Circuits

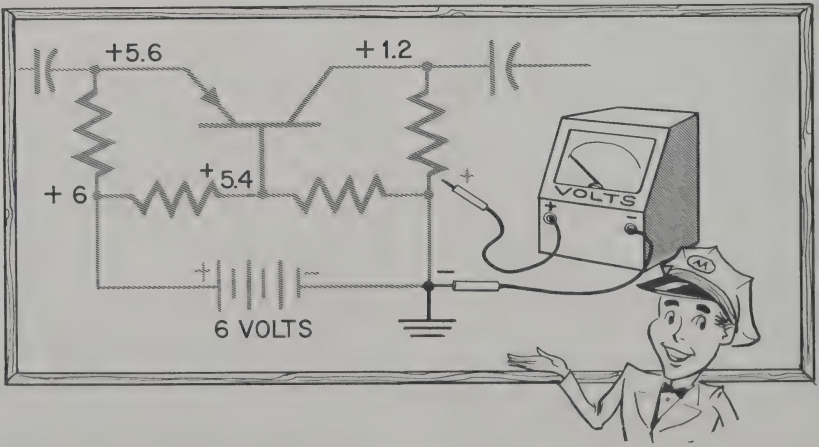
Although the common-emitter circuit provides the greater gain where the impedances are suitable, occasionally a certain stage has characteristics which make it advisable to use the common-base configuration. There are several such instances in Motorola equipment.

Figure 6 shows the bias arrangement of an RF amplifier stage used in a high-band mobile receiver. The supply voltage has a negative ground, which means that the collector may be returned directly to ground through its load, a tuned circuit. For all practical considerations, the collector is at ground DC potential.

Resistors R1 and R2 are the now familiar voltage divider across the supply voltage, with the base returned to the midpoint. The biasing voltage at the emitter-base terminals is the voltage of R1 minus the voltage drop of emitter resistor RE. This resistor serves as the emitter return resistor and as a DC stabilizing resistor. Bypass capacitors are introduced in order to avoid loss of gain due to degeneration.

Figure 7 shows the circuit of a high-frequency (12 mc) IF stage used in a pocket-size, high-band receiver. The positive side of the supply is grounded. The emitter returns to ground through a resistor and the collector is connected directly to the negative side of the battery as far as DC is concerned, for there is no appreciable DC voltage across the coil of the tank circuit.

Resistor R2 of the voltage divider provides for the desired amount of bias voltage between the emitter and base, with the drop across emitter resistor RE opposing the voltage of R2. The voltage across resistor R1 is the reverse collector bias.



With the Negative Side of the Supply Grounded, All the Circuit Terminals are "Positive." To Make Voltage Checks, Ground the Negative Test Lead.

Common-Collector Bias Circuits

The biasing methods for common-collector circuits are similar to those of the preceding figures. Figures 8 and 9 show several variations, depending upon the nature of the source voltage.

In figure 8 the supply voltage is "negative" by virtue of the positive terminal of the battery being grounded. The collector is grounded as far as AC is concerned, and this is realized by the capacitor between collector and ground. As far as DC and bias are concerned, however, the collector is above ground, for it is connected directly to the negative terminal of the battery.

Resistors R1 and R2 are the voltage divider, with the emitter-base voltage being equal to the difference in the voltages of R2 and RE. The voltage across R1 is the collector reverse bias.

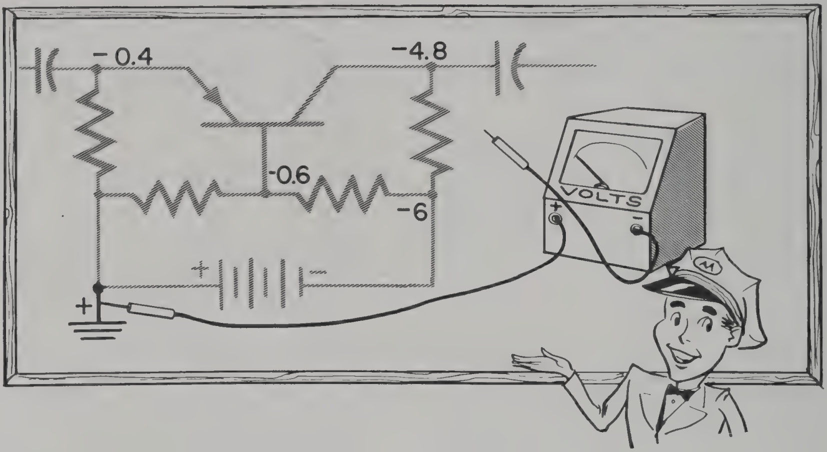
Figure 9 shows a method of biasing the common-collector circuit when the supply voltage has a negative ground. The collector is now connected directly to ground and the emitter returns to the positive side of the supply through the load, RE. Voltage divider resistors R1 and R2 provide the required voltage to the base circuit, with the final emitter-base voltage being equal to the voltage of R1 minus the voltages of RB and RE.

Temperature and Transistor Stability

There are two effects of temperature taking place within the transistor which are detrimental to its operation. First, as the temperature increases, both its power handling ability and its ability to amplify decrease. In fact, if the transistor becomes too hot it is likely to be permanently damaged. The second undesirable effect of transistor temperature is the normal change of DC currents through the transistor with changes of temperature: as the temperature increases the currents also increase.

At this time we will not concern ourselves with the fact that extreme temperatures may damage the transistor, for the low-power transistors we are discussing are not likely to develop sufficient internal heat to cause damage when used in their typical "RC" circuits. Their temperature does increase some as a result of the currents through the junctions, however, and this heat causes an increase of current. Thus, it is essential to introduce some protection or compensation in the circuit which counteracts and limits any current change.

Without going into details of how it happens, we can readily observe on meters that the currents through a transistor increase with an increase in transistor temperature--



Where the Positive Side of the Supply is Grounded, All the Circuit Terminals are "Negative." Ground the Positive Test Lead of the Meter for Voltage Measurements.

see figure 10. With a given forward bias for the emitter and a reverse bias at the collector, the meters record a specific value of emitter and collector current. Without some means of compensation, if the temperature of the transistor increases, the currents also increase.

When we consider that the stage is operating as an amplifier and that it is essential to maintain certain values of DC current for proper operation, we can readily visualize that any major change in the circuit currents can change the characteristics of the amplifier. This is particularly true of transistor amplifiers.

Something must be done to stabilize the DC currents of the stage for changes of temperature. This may be accomplished in several ways, but the most common methods seem to be (1) a series-connected resistor in the emitter circuit and (2) a resistor placed between the collector and base. We will now see the operation of each of these arrangements.[1]

Emitter Stabilizing Resistor

We have already seen the resistor in the emitter circuit and found that the voltage across this resistor opposes the bias voltage to the emitter junction. It is this action which tends to stabilize the DC operation of the stage.

Figure 11 shows a very simple circuit in which one battery is used for bias. The emitter-base forward bias is the voltage across R1, less the voltage across RE.

---

1. See Basic Theory and Application of Transistors (TM11-690), pages 85-86.

Depending upon the transistor, the bias voltage and the value of the resistors, a certain amount of DC current is established at the emitter junction. We are now ready to see what happens when the currents through the transistor increase due to an increase of transistor temperature.

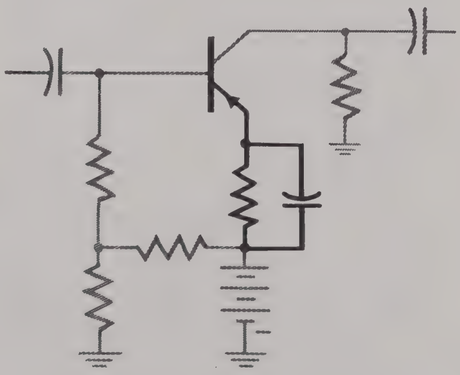
As the emitter current increases, due to an increase of transistor temperature, the voltage across the emitter resistor also increases. An increase of voltage across RE means that the emitter becomes more negative; a negative-going emitter means that there is a decrease in the forward bias voltage, and the current must decrease.

Thus, the increase of voltage across the emitter resistor causes a reduction in current, with the final result that the initial increase due to the temperature rise has been minimized. The net change of current is small--so small, in fact, as to have no appreciable effect upon the operation of the stage.

The emitter resistor in the circuit of figure 11 is a self-biasing type of resistor in which the changes of current through the resistor produce an opposing change in the forward bias. This is almost identical in effect with the bias voltage developed across the self-biasing resistor in the cathode circuit of a vacuum tube amplifier.

We must keep in mind that the changes we have been talking about so far in figure 11 are DC changes which occur over a period of time--they are not the changes due to an applied signal. Thus, the emitter resistor provides protection from undesirable changes of operation due to temperature changes of the transistor.

In addition to this protection from changes in operation due to temperature changes, the emitter resistor also maintains a more constant operation as the transistor ages; for any long-term variations in the DC currents, regardless of their origin, the resistor provides a compensating voltage which minimizes such changes. Thus, the resistor is also beneficial in maintaining more stable operation if a transistor having slightly different current characteristics is substituted for the original transistor.



The Emitter Resistor Provides DC Stability to the Transistor Amplifier; the Bypass Avoids Degeneration Due to the Resistor.

The emitter resistor is incorporated in many amplifier circuits, although in most cases it is necessary to use a large bypass capacitor in parallel with the resistor in order to avoid degeneration and loss of gain in the amplifier.

Figures 12 and 13 show why the unbypassed emitter resistor is degenerative as far as the applied signal and stage amplification is concerned. That is, it produces changes of voltage which oppose the normal changes of current at the emitter junction, thereby reducing the amount of change (signal variations) in the output circuit.

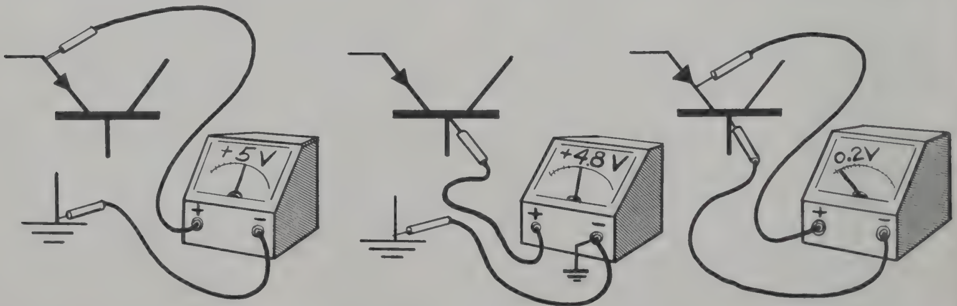
Figure 12 shows the action when the negative portion of the signal is applied to the base of a PNP transistor. The base is driven negative by the signal, increasing the forward bias and current at the emitter junction.

An increase in emitter current also causes an increase in the voltage across the emitter resistor. This means that the emitter swings in a negative direction and reduces the forward bias. This action tends to cause a decrease in the emitter current, but what actually happens is that it opposes the increase taking place as a result of the negative signal applied to the base.

The over-all effect is that the emitter current does not increase as much as it would if the emitter resistor were omitted. With less change of emitter current, there is less current change in the collector circuit, lowering the overall "gain" of the stage.

Figure 13 shows the same effect taking place during the positive half of the signal. That is, the change of voltage across the emitter resistor opposes the change initiated by the signal.

With the base going positive, the forward bias of the emitter junction is reduced and the emitter

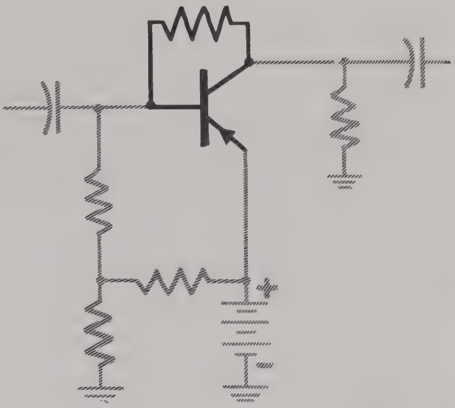


To Determine the Forward Emitter Bias, Measure the Separate Voltages at the Emitter and Base, Both with Respect to Ground. The Difference in the Readings is the Forward Bias. This is Usually More Accurate than a Reading Secured Directly Between the Emitter and Base.

current decreases. This lowers the emitter resistor voltage and the emitter becomes less negative--in effect, it swings positive. A positive going emitter means an increase of emitter current. Of course, the current does not increase, but the original decrease, initiated by the applied signal, is counteracted and becomes a smaller decrease.

The degenerative effect of the changing emitter resistor voltage may be avoided by using a large bypass capacitor across the resistor--see figure 14. This capacitor, assuming it to be sufficiently large to prevent any changes of voltage across the resistor at the signal frequency, maintains a constant voltage at the emitter with respect to ground and thereby prevents the degeneration. Now, the only change at the emitter junction is caused by the applied signal; the stage has been restored to full amplification.

In order for the emitter bypass capacitor to be effective, it must have a reactance which is one-tenth or less the internal resistance of the emitter junction, and this must be at the lowest frequency involved. For an audio amplifier, where both the applied frequency and the emitter resistance are low, this bypass capacitor is usually 50 mfd or larger. This means that an electrolytic (often a tantalum type) is required--fortunately a low-voltage unit will suffice.



The Collector-Base Resistor Gives Good DC Stabilization, But It Also Introduces Degeneration.

Although the resistor is bypassed and its voltage does not change or vary with the signal frequency, this does not have any effect upon the DC stabilization ability of the resistor. Gradual changes of current, taking place over a period of time with changes of temperature, will still cause a change of voltage across the emitter resistor and thereby stabilize the circuit. Thus, while the bypass prevents changes of voltage at signal frequencies, it does not affect those changes taking place over a longer period of time.

Collector-Base Stabilizing Resistor

Figure 15 shows another practical method of providing DC stability in an amplifier. Without the collector-base resistor of figure 15, normal changes of DC current, taking place as a result of temperature changes, will alter the operation of the stage.

The collector-base stabilizing resistor is somewhat similar in its operation to the emitter resistor we have just studied. The base-emitter voltage is determined by the voltage drops across collector resistor RC and stabilizing resistor RB. (The resistor between the base and ground is sometimes omitted, but the operation remains the same.)

As the voltage drops across either or both resistors increase, the base becomes less negative, or, in effect, it swings positive. Conversely, reduced current through either of these resistors causes an increase in the negative voltage of the base with respect to ground, which is an increase in bias. We can now see how this stabilizes the circuit.

Looking at figure 15, assume that the transistor temperature increases and initiates an increase in the emitter-collector current. This increases the voltage drop across the collector resistor and makes the base less negative, which, in effect, is a change in the positive direction. With the base less negative, the forward bias of the emitter-base junction is reduced and lowers the conduction of the transistor. This opposes the original increase in the transistor currents so that the net change is a minimum.

The opposite effect takes place for reductions in transistor temperature. The reduced current and the voltage of the collector resistor makes the base swing negative, thereby increasing the forward bias and opposing the decrease.

Unfortunately, the stabilizing effect of the collector-base resistor of figure 14 also introduces degeneration of the applied signal. When the collector current increases or decreases due to the applied signal, the changing voltage at the base (as a result of the changing voltage drop across the collector resistor) opposes the initial change of current. This means that the gain is lower than that which could be realized without this resistor.

Also unfortunate is the fact that the stabilizing resistor between the collector and base cannot be bypassed as was done for the emitter stabilizing resistor. A bypass capacitor parallel with the resistor would introduce a short between the input and output circuits.[2]

This concludes our discussion about transistor bias and DC stabilization. We will see how these principles are used in practical audio and higher frequency applications in the next two lessons.

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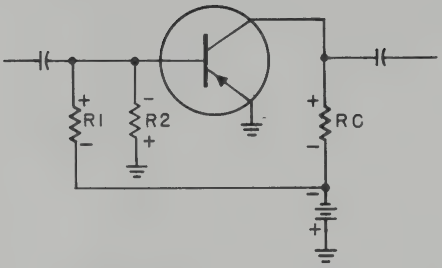
[2] See TM11-690, pages 87-91.

STUDENT NOTES

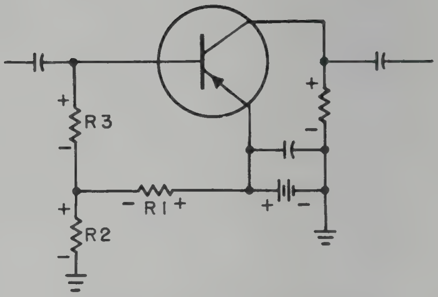
STUDENT NOTES

STUDENT NOTES



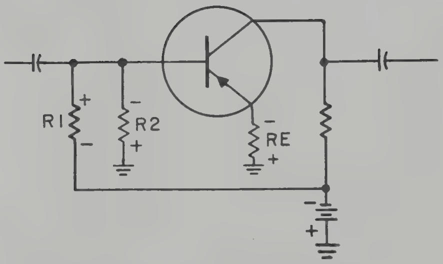
COMMON-EMITTER BIAS CIRCUIT
FOR "POSITIVE GROUND" SUPPLY

FIGURE 1



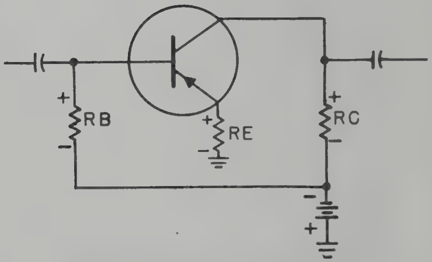
COMMON-EMITTER BIAS CIRCUIT
FOR "NEGATIVE GROUND" SUPPLY

FIGURE 2



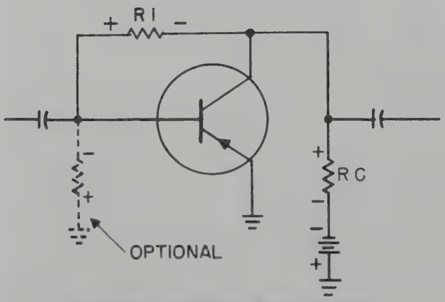
COMMON-EMITTER BIAS CIRCUIT
INCLUDING EMITTER RESISTOR

FIGURE 3



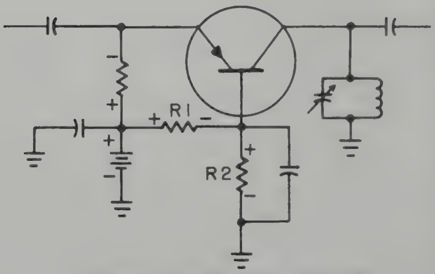
COMMON-EMITTER BIAS CIRCUIT

FIGURE 4



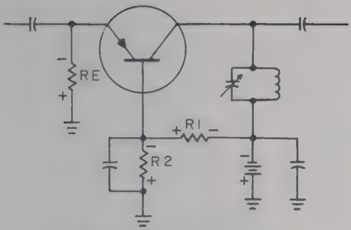
COMMON-EMITTER BIAS CIRCUIT
--COLLECTOR—BASE RESISTOR--

FIGURE 5



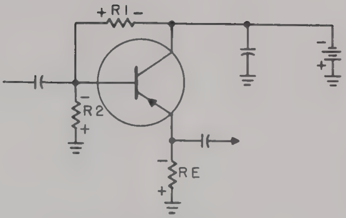
COMMON-BASE BIAS CIRCUIT
FOR "NEGATIVE GROUND SUPPLY

FIGURE 6



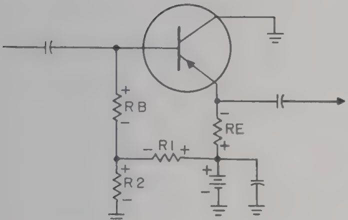
COMMON-BASE BIAS CIRCUIT
FOR "POSITIVE GROUND" SUPPLY

FIGURE 7

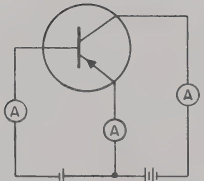


COMMON-COLLECTOR BIAS CIRCUIT
FOR "POSITIVE GROUND" SUPPLY

FIGURE 8



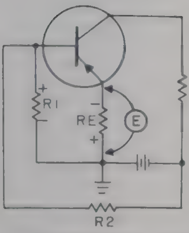
COMMON-COLLECTOR BIAS CIRCUIT
FOR "NEGATIVE GROUND" SUPPLY
FIGURE 9



AMMETERS PLACED IN THE EMITER, COLLECTOR AND BASE CIRCUITS SHOW AN INCREASE OF CURRENT WITH AN INCREASE OF TEMPERATURE.

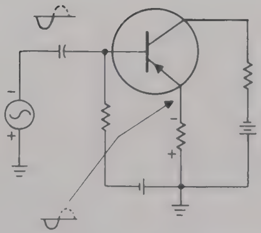
TRANSISTOR CURRENTS VS TEMPERATURE

FIGURE 10



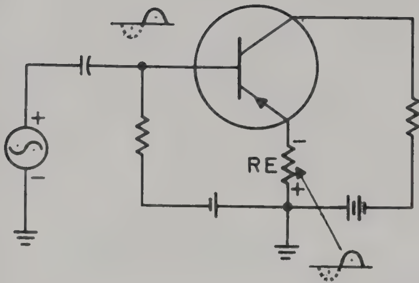
VOLTAGE E OPPOSES OR COUNTERACTS THE BIASING VOLTAGE. AS E INCREASES THE FORWARD BIAS DECREASES AND VICE VERSA.

TEMPERATURE STABILIZATION OF DC
OPERATION BY UTILIZING EMITTER RESISTOR
FIGURE 11



1. ON NEGATIVE SIGNAL SWING THE FORWARD BIAS INCREASES.
2. THE EMITTER CURRENT INCREASES.
3. THE EMITTER-GROUND VOLTAGE INCREASES.
4. THE EMITTER SWINGS MORE NEGATIVE.
5. THE NEGATIVE GOING EMITTER OPPOSES THE ORIGINAL CURRENT INCREASE.

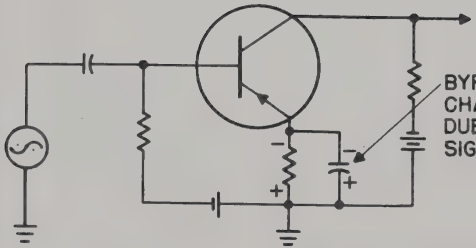
SIGNAL DEGENERATION DUE TO
EMITTER RESISTER ON NEGATIVE INPUT
FIGURE 12



1. ON POSITIVE SWING OF SIGNAL THE FORWARD BIAS DECREASES.
2. THE CURRENT AND VOLTAGE AT THE EMITTER RESISTOR ALSO DECREASE.
3. THE EMITTER SWINGS POSITIVE (LESS NEGATIVE TO ⏚).
4. THIS POSITIVE EMITTER SWING OPPOSES THE ORIGINAL REDUCTION IN CURRENT.

SIGNAL DEGENERATION DUE TO EMITTER RESISTOR--DURING POSITIVE INPUT

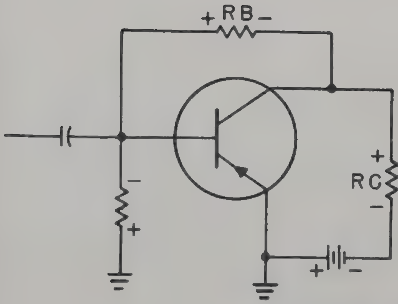
FIGURE 13



BYPASS CAPACITOR PREVENTS ANY CHANGES OF VOLTAGE AT EMITTER DUE TO CURRENT VARIATIONS AT SIGNAL FREQUENCIES.

EMITTER BYPASS AVOIDS DEGENERATION

FIGURE 14



1. AS TEMPERATURE INCREASES BOTH THE CURRENTS AND VOLTAGES OF RC AND RC INCREASE.
2. THE BASE IS NOW LESS NEGATIVE, OR, IN EFFECT IT HAS SWUNG POSITIVE.
3. THE FORWARD BIAS IS DECREASED, OPPOSING THE ORIGINAL CURRENT INCREASE.

DC STABILIZATION, USING COLLECTOR-BASE RESISTOR

FIGURE 15

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Name ______________________________ Student No. ______

Street ________________ Zone ____ Date ______

City ______________ State ________ Grade ______

EXAMINATION, LESSON SA-5

1. Figures A and B are common-emitter transistor circuits with the base circuit incomplete in each instance. Using only the battery supply of the figures, show how the base can be connected in both circuits to provide forward bias of the emitter junction.

2. In figures A and B, (1) indicate the correct polarities of the battery supplies, and (2) indicate the polarity of voltage drops across all the resistors.

3. In figure C, the various transistor elements have the indicated voltages as measured with respect to ground. The bias voltage of the emitter-base junction is (1.0 volt) (0.8 volt) (0.2 volt) (1.8 volts) and this is a (forward) (reverse) bias.

4. In figure C, if the transistor temperature rises, the transistor DC currents also rise. As a result, the following takes place. The voltage drop across the emitter resistor (increases) (decreases), and the forward bias of the emitter-base junction (increases) (decreases). This causes (an increase) (a decrease) in the transistor currents and (aids) (opposes) the original increase.

5. In a temperature stabilizing system for transistor amplifier stages, the purpose is to avoid changes in the DC operating characteristics of the circuit as a result of temperature variations within the transistor but not to interfere with the operation of the stage as an amplifier. TRUE______ FALSE______

6. Figure D is an incomplete common-base circuit using a PNP transistor. Show a base circuit which will provide the proper bias voltages at the junctions. Indicate the polarity of voltage drops across all the resistors.

7. In figure D there is a resistor between the emitter and supply. May this resistor be bypassed in an effort to prevent degeneration across the resistor? YES______ NO______

8. The emitter resistor used for DC stabilization is usually bypassed to: (Choose more than one answer).
   A. Make the circuit operate as a stabilizer for DC. Without this bypass the circuit will not be DC stabilized.__________.
   B. Keep the emitter voltage constant by preventing sudden changes of current through the resistor.__________.
   C. Prevent AC or signal degeneration. __________.
   D. Keep the DC voltage across the resistor from becoming too large. __________.

9. Where a bypass is used, the low impedance and resistances of the circuit and the fact that low frequencies are involved means that the bypass must be a relatively small unit (small capacitance). TRUE______ FALSE______.

10. Which circuit in figure E is DC stabilized? A__________ B__________.

FIGURE A

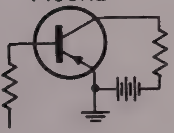


FIGURE B

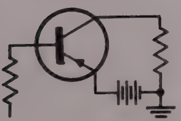


FIGURE C

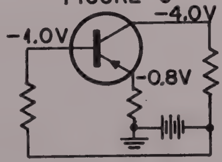


FIGURE D

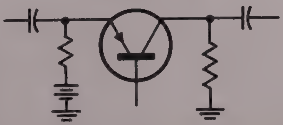
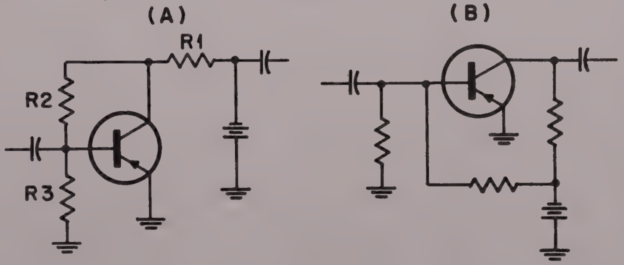


FIGURE E



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A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON SA-6
TRANSISTORS

Transistorized Audio Equipment

—one of a series of lessons on two-way FM communications—

MOTOROLA TRAINING INSTITUTE
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PREFACE

This is one lesson of a complete Motorola Home-Study Course which presents to the Service Technician both the principles of operation and the maintenance of two-way FM radio systems. The program covers mobile, portable and base station equipment, including the latest transistorized units.

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TRANSISTORIZED AUDIO EQUIPMENT

LESSON SA-6

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NOTICE

Diagrams and figures referenced in text are “fold-outs” in back of each lesson, for use while studying. The Examinations are also there.

A transistorized "Power Voice" megaphone is used by shipyard dockmaster. The high audio output of unit enables him to direct drydocking of coastal vessel.

TRANSISTORIZED AUDIO EQUIPMENT

Lesson SA-6

Introduction

In our study of the transistor thus far, we have learned about its basic principles of operation; we found that the transistor is a current controlling device. That is, the gain of the transistor amplifier depends upon both the current gain and the impedance gain of the transistor. We also learned about the three configurations which may be used in amplifiers, being the common-base, common-emitter, and common-collector circuits. In studying transistors we also discovered that the same methods and problems of coupling encountered with vacuum tubes apply to transistor stages.

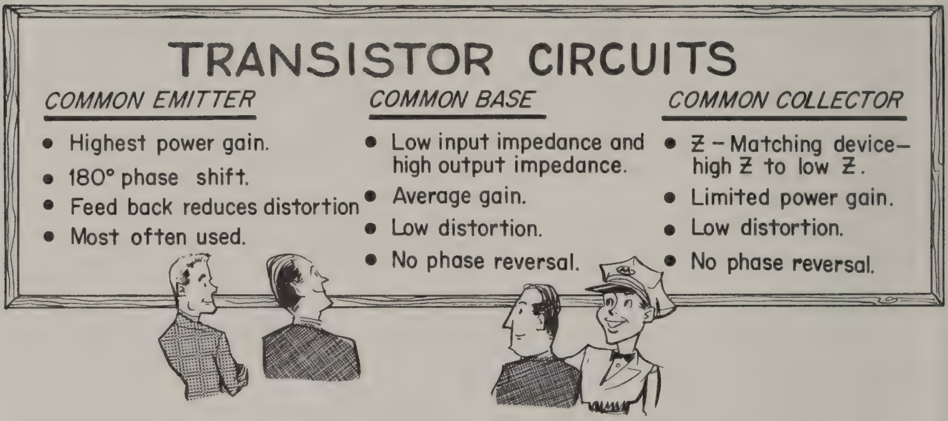
In this lesson we shall apply what we already know to various low-frequency circuits found in Motorola communications equipment. While we have talked about low-power transistors thus far, in this lesson we shall also discuss transistors and audio stages capable of greater amounts of power. Before proceeding with these matters, however, we shall make a short review of transistor operation.

Transistor Circuits and Characteristics (Review)

The chart of figure 1 summarizes the characteristics of the three transistor circuits. Due to its high current gain and medium impedance gain, the common emitter gives the greatest power gain, requires the least amount of input power for a given power output, and is the most often used. The common-emitter circuit gives a phase shift of 180° from its input to its output, although there are but few applications where this is of particular importance.

There is one disadvantage of the common-emitter arrangement, in that it gives the greatest amount of distortion. Due to its high gain, however, it is possible to introduce feedback, thereby reducing the distortion but, at the same time, maintain a reasonable gain.

There are certain applications where the common-base circuit is the most satisfactory to use--where the source impedance is low and the load impedance high. The gain of the common-base circuit is average, the distortion is rela-



TRANSISTOR CIRCUITS

COMMON EMITTER

- Highest power gain.
- 180° phase shift.
- Feed back reduces distortion
- Most often used.

COMMON BASE

- Low input impedance and high output impedance.
- Average gain.
- Low distortion.
- No phase reversal.

COMMON COLLECTOR

- Z – Matching device– high Z to low Z.
- Limited power gain.
- Low distortion.
- No phase reversal.

Each Transistor Circuit Has Its Specific Characteristics and Application.

tively low, there is a medium amount of isolation between the input and the output circuits, and there is no phase reversal between the input and output signals.

The common-collector circuit finds its main application as a means of impedance matching a high-impedance source to a low-impedance output. There is no voltage amplification for this stage and only a limited amount of power gain. In addition, the input and output circuits are very interactive, the distortion is low due to the high amount of feedback inherent to the circuit, and the output signal is in phase with the input.

Coupling Methods (Review)

We found in our study of coupling methods that the same problems and methods of coupling inherent to vacuum-tube circuitry are applicable to transistor stages. For audio circuits, RC and transformer coupling are the most popular, although direct coupling is also sometimes employed.

Transformer coupling has the advantage of providing an impedance match which, in turn, allows maximum gain. Transformers, however, are relatively expensive and are not conducive to the construction of lightweight, compact equipment. Transformers have their greatest application where the audio signal is relatively large and the power level is high.

RC coupling is most often used where the signal is small and the power level is low. Thus, in audio equipment, we expect to find RC coupled stages as the first few stages of the amplifier, but not in the final stages. In general, RC circuitry is used where the power level is below 100 milliwatts (0.1 watt). For high power stages, transformers are usually necessary.

Direct coupling is also encountered in certain audio equipment, but it is not used extensively because of the difficulty of providing temperature stability. We will see at least one application of DC coupling as we study the various audio stages of Motorola equipment.

We have just completed our brief review of transistor circuitry and are ready to proceed with our study of transistorized audio amplifiers. The first new subject matter to be discussed is feedback and distortion.

Feedback and Distortion

It is common practice to use degenerative feedback to offset the distortion inherent to transistor amplifiers. In addition to providing degeneration, the feedback often gives DC stabilization. The reduction of distortion due to degenerative feedback is approximately equal to the loss in gain. In the preceding lesson we found two types of DC stabilization which could also be used to provide a certain amount of degenerative feedback. These are the unbypassed emitter resistor and the resistor between the collector and base.

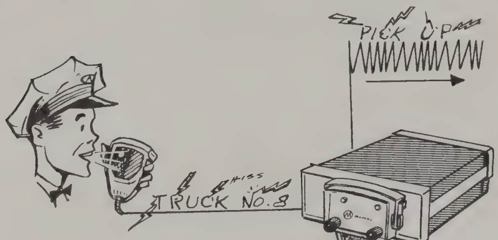
Referring to figure 2, the varying voltage across an unbypassed emitter resistor in the common-emitter circuit reduces the effective signal voltage between the base and emitter, thereby lowering the over-all stage gain. However, the distortion is reduced by a nearly equal amount. The reduction in gain due to the emitter resistor depends on the source and load impedances as well as on the value of the resistor and the characteristics of the transistor. This emitter resistor has the effect of raising the input and output impedances.

Figure 3 shows another type of degenerative feedback commonly encountered in the common-emitter circuit. Feedback resistor RF applies some of the output voltage to the input, and this feedback voltage is of such phase to oppose the signal voltage.

Consequently, the effective signal voltage is reduced and the gain is lowered. This feedback reduces the input and output impedances instead of raising them as in the case of the unbypassed emitter resistor.

In the above arrangements, distortion is reduced by introducing degenerative feedback within a single stage. Feedback (and consequent improvement in amplifier response) can also be applied around a number of stages, but far more care in design is required. In general, greater stability and control of the amount of reduction of distortion can be obtained by introducing the feedback within an individual stage. Feedback introduced by this method is more effective over the entire audio range, and the response is more linear.

Where a feedback loop is provided for three or more stages, phase shift within individual stages at the higher frequencies is likely to produce sufficient regeneration to cause oscillation. That is, the feedback at the lower frequencies may be degenerative, but the phase shift at the higher frequencies may be regenerative and cause oscillation.



Without a Preamplifier, the Weak Audio Signal from the Microphone Must Compete with the Noise Pickup in the Audio Lines.

Transistorized Microphone Preamplifier

The dynamic microphone and preamplifier has two distinct advantages over the previously used carbon microphone: there is (1) a decided improvement in frequency response and (2) less background noise. Because of the relatively low output of the dynamic element, however, it is necessary to provide an additional stage of amplification.

The transistor affords a very practical means of locating the amplifier right in the microphone housing rather than at the transmitter chassis; this allows a better signal-to-noise ratio of the modulating signal. If the amplifier were located at the transmitter itself, any noise picked up between the microphone and the amplifier would be amplified right along with the audio. By using the preamplifier in the microphone housing, the audio signal is built up before any noise is introduced and there is no need for any additional preamplification at the transmitter chassis. The audio signal may now be applied directly to the audio section of the transmitter.

The transistor requires only a low value of DC voltage and current for its operation, and it is practical to supply this through the microphone cable. In fact, the DC formerly supplied to the carbon microphone element may be used for the amplifier. This arrangement is not so simple for a vacuum-tube preamplifier, where both filament and plate power are required.

The microphone preamplifier shown in figure 4 is very similar to those which we have been discussing in the preceding lessons. A PNP low-power transistor is used in a common-emitter circuit; junction bias is provided by the voltage divider consisting of resistors R1 and R2. The emitter-base bias is the voltage of R1 less the voltage developed across stabilizing resistor RE. The voltage across R2 is the collector-base reverse bias.

The electrolytic condenser prevents degeneration of the audio signal across the emitter resistor and allows for maximum gain. The return path for the base is through the dynamic microphone element. The microphone has a low impedance, about 50 ohms, which provides for an easy match to the input of the amplifier.[1]

A small, 10-ohm resistor in the emitter return circuit, which may be shorted out at the factory when the microphone is tested, affords a means of compensating for the normal variations of gain which occur in transistors of the same type.

This resistor is not bypassed and hence it is degenerative if left in the circuit. For transistors of average gain, then, the resistor must be shorted so that the amplifier has full gain; for transistors of high gain, however, the short is removed so that the resistor is in the circuit and the gain of the stage is reduced. This resistor allows all microphones, in connection with their preamplifiers, to have the same output voltage, the design center being 0.17 volt.

If microphones of widely varying output voltages are used with a particular transmitter, one of two conditions will occur. First, if the deviation of the transmitter is adjusted according to a microphone having a high output, other microphones with less output voltage will not produce full deviation, and they will sound weak and possibly noisy in the receiver.

A Preamplifier Produces a Strong Audio from the Microphone, Thereby Avoiding the Problem of Noise Pickup.

Second, if the transmitter deviation is adjusted according to the output of a "weak" microphone, other microphones having higher output voltages will overdrive the IDC circuit and cause excessive clipping. This produces nonlinear deviation at the transmitter, which means unnecessary distortion of the message at the receiver.

The output voltage of the dynamic microphone and its preamplifier has about the same amplitude as the carbon microphone and can be substituted directly for the carbon microphone in almost all Motorola transmitters. (It may be necessary to readjust the IDC control.)

Transistorized IDC Circuit

Portable Motorola equipment includes a transistorized version of the IDC (Instantaneous Deviation Control) circuit. The purpose of this section of the transmitter

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1. See Basic Theory and Application of Transistors (TM11-690), pages 112-116.

is the same regardless of whether we use vacuum tubes or transistors. That is, the amount of deviation produced at the modulator must be limited to a specific amount and, as we know from our previous discussions about IDC, this requires a control of both the amplitude and the waveform of the modulating signal. (An increase of either frequency or amplitude of the modulating signal at the phase modulator increases the amount of deviation.)

Figure 5 shows the arrangement of the transistorized IDC circuit. Only one stage is used; it provides a certain amount of amplification for the small audio input, but it also limits the output of stronger signals. The 2N217 transistor used as the amplifier-clipper is a low-power, PNP unit. The B supply is used as the bias voltage source with R3 providing the necessary drop to 9 volts, the actual supply voltage for the stage. Voltage divider R1 and R2 plus emitter resistor RE provide the optimum emitter-to-base bias.

The base is less positive than the emitter, so the emitter junction is forward biased and allows collector current. As soon as current is established through the emitter resistor, the resulting voltage drop makes the emitter less positive and the emitter junction forward bias is reduced. The difference between the base and emitter potentials is the effective bias voltage, in this case 0.1 volt.

The over-all action of this circuit is essentially the same as that of the corresponding vacuum-tube version. The transistor provides amplification for signals below a predetermined level, but for those signals above this level the transistor goes into clip--the output voltage cannot increase above a certain predetermined level. (We shall speak of this limiting action in greater detail in the next lesson.)

Following the clipper, the integrator and the splatter filter further alter the audio waveform to resemble a sinewave, thereby reducing the harmonic content of the wave and avoiding overdeviation, splatter and distortion.

One more factor in this circuit, is the natural 6-db per octave deemphasis characteristic of the integrator. In order to maintain a flat response within the stage, a differentiator is included in the input, and this has a 6-db per octave preemphasis. In figure 4 this differentiator is capacitor C1 and the input impedance (resistance) of the transistor.

Figure 5 includes the waveforms which result from signals above and below the clip level. Sinewaves having considerable amplitude become square waves at the collector and triangular waves at the modulator input. Signals which are partially clipped become more trapezoidal at the collector and more sinusoidal at the output.

The Power Transistor is Large and Usually Has Its Collector Grounded to the Frame for Efficient Heat Dissipation.

The output of the transistor (the collector circuit) has a low impedance (about 10,000 ohms) compared to the inherently high impedance of the modulator grid. Transformer T1 provides for this difference of impedance; it has a primary of 10,000 ohms and a 250,000-ohm secondary. R4 and C2 comprise the integrator; L1 and C3 make up the waveshaping circuit, limiting the high-frequency energy and hence the splatter.

Potentiometer R5 at the output is the IDC control. It is preset at the factory and need not be readjusted unless there has been some reason for changing it. Where the transmitter is improperly deviated, it is best to locate the original source of the trouble and to correct it, rather than compensate for the trouble by means of the IDC pot.

This completes our discussion of transistorized low-power audio stages. The next audio stages to be discussed make use of transistors capable of handling a considerable amount of current and power. We shall now have a look at these transistors and their operating characteristics.

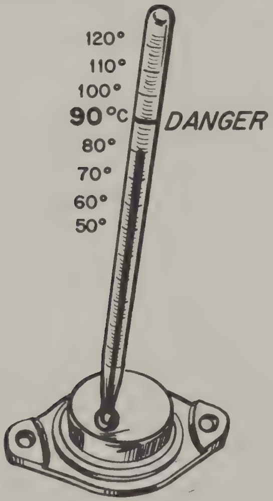
Power Transistors

Power transistors are physically much larger than the "low-power" transistors we have been discussing up to this point. The transistor elements alone does not require any great space, but the associated assembly is made large in order to provide for good heat conduction. The currents which pass through the junctions generate considerable heat, and this heat must be dissipated if the transistor is to operate as intended.

A close inspection of the power transistor shows one of its elements (usually the collector) in physical contact with the transistor mounting base. This helps to transfer the heat away from the junction to the mounting base, and from the mounting base the heat is transferred to a "heat sink," whence it is radiated into the surrounding space.

In order to provide good heat transmission away from the junction (as well as good electrical conduction), copper and similar materials are used extensively in the construction of power transistors. The semiconductor material from which the transistor is made has a lower heat conduction than copper, which partially accounts for the higher temperature at the collector junction.

The maximum recommended junction operating temperature of the average power transistor is approximately 90°C (194°F). This temperature rating is determined not by the physical construction of the transistor, but by a gradual deterioration known as "aging."



The Temperature (Internal) of Germanium Power Transistors Should Not Exceed 90°C.

At temperatures above 90°C, but still below the melting point of the transistor materials, both the normal increase of the internal leakage current (I_{CO}) and the accompanying decrease in current amplification (h_{fe}) are accelerated, so that the transistor ages prematurely and the unit soon becomes inefficient. This 90°C rating thus represents a compromise between power dissipation and the accelerated aging of the transistor.

The maximum permissible collector junction dissipation is determined by the ambient temperature. Any power dissipated in the collector junction causes an increase in temperature. Therefore, if the ambient temperature is already the maximum which is allowed, any further increase, due to collector dissipation, will overheat the transistor. Thus, the ambient temperature must always be less than the maximum allowed temperature.

Power Transistor Limitations

The operation of power transistors is limited by two inherent characteristics. First, the current amplification factor changes with the emitter current. Second, the input impedance is not linear.

Figure 6 shows the variations in amplification factor exhibited by power transistors as the emitter current increases. Consider first the curve for the "non-doped" junction. With an emitter current of less than one-half ampere, the amplification factor (h_{fe}) is greater than 50. As the emitter current increases, however, the amplification factor decreases; for currents greater than 3 amperes, the amplification factor is less than 10. These values are for power transistors having indium emitters.

When a small amount (about 2%) of aluminum or gallium is added to the emitter, the amplification factor of the transistor does not decrease as rapidly for increases of emitter current. Consider the curve for the "doped" emitter junction in figure 6. At currents greater than 2 amperes the amplification factor is at least twice that of the non-doped junction. Also important is the fact that the doped junction shows considerably less over-all change in its amplification factor between low and high values of current.

The nonlinear input impedance of power transistors is also an important consideration. If we are to avoid distortion in the output as a result of this nonlinear input impedance, it will be necessary to establish a sinusoidal change in the input current; it is not sufficient merely to apply a sinusoidal voltage.

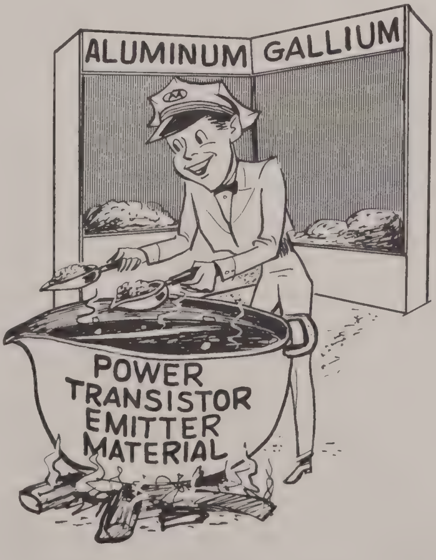
If the impedance of the source is high compared to the input impedance of the transistor, the change of impedance within the transistor will have but little effect upon the current. The end result is that a sinusoidal signal voltage will cause similar current variations.

The degree of non-linearity of the input impedance varies with the transistor configuration. The common-emitter circuit shows a greater variation of input resistance than either of the other configurations, so it is likely to cause the most distortion in the average circuit.

While the common-collector and common-base configurations cause less distortion, they also provide less power gain than the common emitter. Thus, the choice of circuitry depends upon the stage requirements; we must sacrifice one or the other, either gain or distortion.

The Power Amplifier

Most of the problems encountered in vacuum-tube power amplifier stages, such as class of operation, impedance matching and distortion, are found also in the transistorized audio power amplifier. The transistor, however,



A Small Amount of Aluminum or Gallium Added to P-Type Emitter Material Provides a More Constant Current Gain in Power Transistors.

has the additional problem of heat dissipation, which is more critical in transistors than in vacuum tubes.

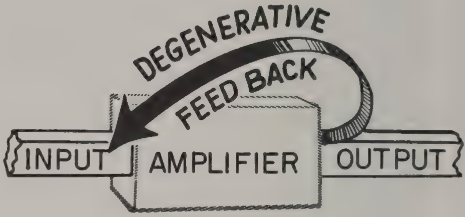
Where a single-ended stage is used, the transistor is operated in Class A in order to keep the distortion at a minimum. Where a greater power output (at higher efficiency) is required, push-pull stages are used. The output transformer must be able to handle the transistor currents, and the transformer turns ratio must provide a suitable match between the output impedance of the transistor and the impedance of the load.

Class A Operation

Where a transistor is operated in Class A, either single-ended or push-pull, the average current does not change appreciably when a signal is applied. With the transistor constantly conducting current, there is heat being generated at all times and this heat limits the power output of the stage.

In Class A operation, only a small amount of the power taken from the supply reaches the speaker (to be converted into acoustical energy). Thus, if we are to have an output of 10-15 watts, the power transistor in the output must be capable of handling a very large collector current.

When the transistor is operated in Class A, the emitter current approaches cutoff and maximum on the positive and negative peaks if any great amount of power is to be delivered to the load. This means that the emitter current varies over its complete range. As we saw (in figure 6), the current gain of the transistor varies with the emitter current and, as a result, one alternation will always be amplified more than the other--the two alternations will not have equal peaks in the output. This asymmetrical output constitutes a very undesirable form of distortion; it limits the permissible swing of the input signal to the final amplifier.



Degenerative Feedback Serves Two Purposes: It Reduces Distortion and Stabilizes the Amplifier.

Push-Pull Amplification

The push-pull power amplifier is a solution to many of the problems associated with the single-ended Class A transistorized amplifier. But, while the transistorized push-pull stage is often described as "Class B," we shall soon see that the operation is more likely to be in Class AB.

Let us first consider the operation of the push-pull Class B transistor amplifier. With no signal applied, each transistor is biased at approximately cutoff and there is very little emitter current. Hence, there is no appreciable amount of heat dissipated in the transistors.

When a signal is applied, each transistor conducts on one alternation, thus operating only half the time; even then the amount of current is determined by the strength of the applied signal. As a result of this class of bias, the average amount of heat generated within the transistor is considerably less than for Class A stages. At the same time, considerably more power output (load power) is realized from the arrangement. Two transistors operating in push-pull, Class B, can deliver about 3.5 times more output power than one transistor of the same type operating Class A.

Figure 7 shows why the push-pull transistor amplifier should not operate in strict Class B, with each transistor biased at cutoff. The transfer characteristic at A applies to Class B, push-pull operation of transistors. At the crossover from one transistor to another, the output current does not start immediately. Moreover, as each transistor completes its half-cycle of conduction, the emitter current reaches zero before the input signal is zero, with the result that there is a discontinuity in the output waveshape (shown to the right in the figure).

The crossover effect, caused by operating the transistors at cutoff, can be overcome by biasing the transistors so that they are slightly conductive without a signal applied. This bias (somewhere between Class A and Class B) is known as Class AB. The initial current established in the transistor is normally somewhere between 1 and 5 percent of the average emitter current with a signal applied; the exact value depends on the characteristics of the transistor.

The transfer characteristic of figure 7B applies to the push-pull operation of a transistor amplifier in Class AB. There is no discontinuity at the crossover points in the output waveform, and the output is a faithful reproduction of the input.

If the forward bias is too great, as at (C), each transistor becomes conductive over a longer portion of the crossover point and the gain of the amplifier at this point is high. As the signal swings toward its peaks, however, one of the transistors becomes nonconductive; the gain is reduced. This effect is shown both in the nonlinear transfer characteristic and in the nonsinusoidal output waveform.

Thus, the operating point of the push-pull amplifier is very important. If we are to avoid distortion in the output, it will be necessary to stabilize this operating point for all changes in temperature.

Temperature stabilization was discussed to some extent in the preceding lesson. The same principles may be applied to the power amplifier so long as the resistor in the emitter circuit is kept at a low value of resistance. (Otherwise, the resulting power loss in the resistor will be intolerable.)

The stabilizing resistor may be bypassed in single-ended or push-pull Class A stages in order to avoid degeneration and loss in gain. The resistor cannot be bypassed, however, in Class AB or Class B push-pull stages. Without the bypass capacitor, the voltage across the resistor varies with the instantaneous current, so that the only effective bias for the stage is that establishing the original bias.

With a bypass capacitor connected across the stabilizing resistor, however, there will be a DC voltage established across the resistor, and this voltage will change with the input signal and with the emitter current. This variable DC voltage produces an additional (and changing) bias on the transistor.

Another source of distortion in the push-pull amplifier is mismatch between the transistors, particularly with respect to their current amplification characteristic. The circuit configuration makes considerable difference in the amount of distortion which results from this mismatch, and the common-collector configuration seems to be the most free from the effects of a mismatch. Although transistors may be matched at the time they are installed, their aging may not be identical with continued operation and a mismatch may eventually occur.[2]

Motorola "Power Voice" Speaker

The average mobile communications receiver, with an audio output limited to a few watts or less, does not drive the speaker sufficiently to overcome loud interfering noises. A practical answer to this problem is the transistorized "power voice" speaker, which operates directly from the vehicle battery. The schematic diagram for the 6/12 volt version of this speaker is shown in figure 8.

The push-pull amplifier operates at Class B, (it is called Class B, but we have just seen that the bias is most likely Class AB); it furnishes 15 watts when operated from a 13.8-volt supply, or 5 watts of power for a 6.6-volt supply. The input to the amplifier is the 3.2-ohm secondary of the receiver output transformer.

The aluminum chassis of the amplifier is the heat sink, for the transistor heat dissipation. The entire amplifier chassis is insulated from the speaker housing, making the polarity of the vehicle's electrical system unimportant. The red lead at the input connects

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[2] See TM11-690, pages 128-132.

Here We See the Transistors and Heat Sink Chassis of a Motorola Power Voice Speaker.

to the positive side of the supply, black is negative. The other two connections are to the secondary of the receiver output transformer; these connections may be made at the control head.

Only one change is required in the wiring in order to operate the circuit on 6 or 12 volts. This connection is at the output transformer secondary. The speaker is connected across the entire secondary winding for 6-volt operation, and to the tap for 12-volt operation. This changes the effective turns ratio; it also reflects a different load impedance.

At 12 volts the 3.2-ohm load of the speaker voice coil, connected to the tap on the secondary, reflects a high impedance into the primary, for the effective turns ratio is high. The result is that the amplifier delivers the full 15 watts of power to the speaker voice coil.

What happens when we change the applied power to 6 volts without changing the tap? With only half as much voltage we can normally expect only half as much current. The net result, as a matter of fact, is that the power at 6 volts is only one-fourth the original value, a change of 6 db. This is less than 4 watts of speaker power. The power is increased by changing the tap of the transformer secondary, effectively lowering the primary impedance.

When the speaker is connected across the entire winding, the turns ratio of the transformer is lowered--there are more secondary turns than before. With a lower turns ratio, the 3.2-ohm speaker voice coil reflects a lower impedance into the primary. The low impedance permits an increase in the current, therefore increasing the power.

Bias for the stage is provided by resistor R2, which is part of the voltage divider (R1 and R2) connected across the primary source. The 0.33-ohm resistors in each of the emitter circuits provide DC stabilization.

"Power Voice" Megaphone

Figure 9 is the schematic diagram of a portable, battery-operated, transistorized megaphone. This unit operates from ten flashlight batteries and delivers 15 watts of audio power.

Two single-ended stages, each operated in Class A, provide the initial amplification for the low-level signals from the microphone, and they are followed by a push-pull driver stage and a push-pull output stage, both operated near Class B. The speaker has a center-tapped, 10-ohm voice coil, which permits it to be used as the load on the output stage without requiring a matching transformer. Interstage transformer coupling is used to drive both push-pull stages.

This 15-Watt, Battery-Operated Megaphone is Made Possible by the Use of High-Power Audio Transistors.

An impedance-matching transformer is used with the microphone to provide the proper input to the base of the first stage. The volume control "pot" is connected in parallel with the transformer secondary. A resistor and capacitor are connected in parallel and placed in series with the input signal. This favors the high frequencies by attenuating the lows; the upper voice frequencies pass without attenuation and the reproduced "message" is made more intelligible.

The first two stages use a common-emitter arrangement, with direct coupling between stages. The output of the second stage is applied to the primary of transformer T1. Resistor R5 between the collector and base provides feedback, both DC and AC, stabilizing the operation of the stage and improving the frequency response.

The secondary of T1 is center-tapped so that push-pull inputs are established at the driver stage. Operated at about Class B, these transistors provide sufficient power to drive the following final amplifier stage.

Both the driver and output stages employ the common-collector arrangement. The 10-ohm resistors in each of the emitter leads of the driver stage provide DC stability to that stage. In the final stage, DC stability is provided by the DC resistance of the speaker voice coil, the same as if a separate resistor were used.

The efficiency of biasing the push-pull stages near Class B can be demonstrated by means of the current drain from the battery supply. With no signal applied (standby operation), the entire circuit draws about 100 milliamperes. At normal voice inputs, the average current drain increases to 1.55 amperes.

Until the trigger switch or the microphone button is depressed, there is no drain on the battery. These two switches (shown in the diagram) are in parallel and they are used to apply the battery voltage to the entire circuit. No warmup time is required for transistors, of course, so the unit is ready for operation the instant either switch is closed.

The biasing system for the power voice megaphone is most interesting; for a simplified diagram of the arrangement see figure 10. As soon as the switch is turned on, the emitter of transistor Q2 is connected to the positive side of the supply line through resistors R6, R7, R9 and R10, and the base of the transistor connects to ground (the negative side of the supply) through resistor R3.

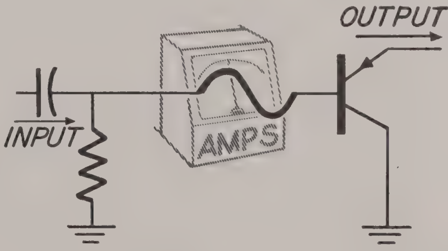
The transistor is now forward biased and conductive. The resulting current (following the positive-to-negative direction) is through resistors R10, R9, R7, R6, the emitter-collector portion of the transistor, and the primary of transformer T1. This circuit becomes a voltage divider across the supply and these voltages determine the forward emitter bias of the other transistor stages.

The voltage across R7 becomes the initial forward bias to Q1 and the transistor conducts. The DC stabilizing voltage across R4 as a result of emitter current alters the final forward bias. A bypass capacitor for R4 in the actual equipment avoids degeneration.

Transistors Q3 and Q4 are biased by the voltage drop across R10. The bases of these transistors connect to the negative side of R10 through the secondary winding of T1 and the emitters connect to the right (positive) side of R10 through the primary winding of T2 and DC stabilizing resistors R11 and R12.

Transistors Q5 and Q6 are biased by the total voltage drop across R9 and R10. The bases of the transistors connect to the left side of R9 through the secondary of T2 and the emitters connect to the positive side of R10, the positive supply line, through the speaker voice coil.

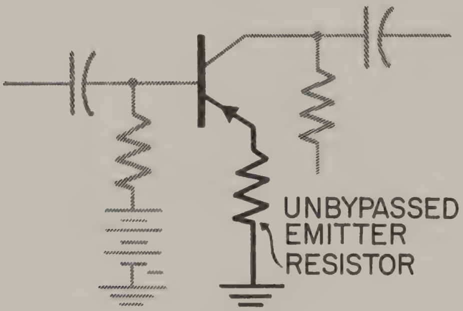
In addition to the audio circuits discussed in this lesson, there is another low-frequency application of transistors which we wish to study--this is the squelch section of Motorola portable and mobile receivers. Before looking at these circuits in detail, however, if you do not recall the principles of squelch operation at this time it may be well to make a quick review of a previous lesson dealing with vacuum-tube squelch circuits.



In Analysing the Transistor Amplifier Input, the Important Consideration Is To Provide a Sinusoidal Current Change for an Applied Sinewave Voltage.

Squelch Circuit of "Portable" Receivers

A large number of Motorola portable receivers, including those of the famous "Handie-Talkie," contain a completely transistorized squelch circuit. As we might anticipate, this squelch is very similar to the vacuum-tube arrangements we have already studied. See the block diagram of figure 11.



The Unbypassed Emitter Resistor Improves the Frequency Response of an Amplifier and Also Reduces Distortion.

Receiver noise, in the absence of a signal, is applied to the noise amplifier, which is followed by a noise rectifier. The DC output voltage of the rectifier, when noise is present, becomes the controlling voltage which biases the audio transistor to the point of nonconduction, thereby closing the squelch. Except for the absence of a DC amplifier between the rectifier and the audio amplifier, this is identical to the vacuum-tube squelch arrangement.

Another difference in the systems is the source of noise voltage. Instead of securing the "noise" from the discriminator, in figure 11 the input to the noise amplifier is the output of the second limiter. We shall discuss this in more detail as we continue with our study of the circuit.

The complete circuit of the transistorized squelch is given in figure 12. Squelch action depends upon a forward or reverse bias at the emitter junction of the audio amplifier. When there is no signal coming into the receiver, the emitter junction of the audio transistor should be reverse biased; when a signal is present, the transistor should be forward biased.

Initial forward bias is established at the emitter junction by returning the base to a fixed negative voltage through resistor R1. With only this voltage applied to the emitter junction, the stage is conductive--the squelch is open. Upon applying a positive voltage to the base circuit (at the upper end of R1 in the figure), the base is made positive to the emitter, the emitter junction is reverse biased, and the stage is nonconductive--the receiver is now squelched.

The positive voltage applied to the control base of the transistor is the output of the noise rectifier. Whenever a high noise level is present in the receiver--when no signal is received--the squelch circuit applies a positive voltage to the base of the audio transistor. When a signal is received, however, the noise quieting of the limiters reduces the input to both the noise amplifier and the noise rectifier, with the result that the positive voltage is removed from the base of the audio transistor and the transistor operates normally--the incoming message is heard.

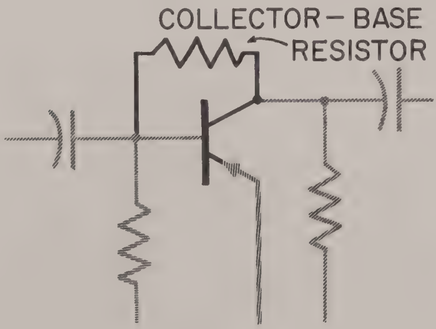
The input to the noise amplifier is taken from the output of the second limiter. A filter (composed of L1, C1, L2 and C2) accepts only the noise components within the higher audio range; the 455-kc IF and the low-frequency voice signals are both attenuated.

This filter is in parallel with C3, which is part of the limiter output. The changes of collector current are not equal for both alternations of the signal during limiting, so that amplitude detection takes place and some AM noise is applied to the noise amplifier. Furthermore, a certain amount of "FM slope detection" takes place for any FM components, either FM noise or FM voice modulations. The input to the noise amplifier is thus similar to that of the noise amplifier of the vacuum-tube squelch circuit, where the input to the noise amplifier is the discriminator output.

The setting of R3 at the input of the noise amplifier determines both the noise level applied to the stage and the output voltage of the noise rectifier. This "pot" is the "squelch control."

The noise amplifier stage, using a PNP transistor in a common-base circuit, is intended to amplify mainly those signals--noise or otherwise--within the upper portion of the audio spectrum. A resistor between the emitter and ground provides DC stability for the stages for changes in temperature; this resistor is bypassed to maintain a reasonable gain.

The output of the noise amplifier is applied to the noise rectifier, which consists of two diodes connected as a voltage doubler and with a positive output voltage. Thus, when noise is applied to the input of the squelch circuit, the positive output voltage from the noise rectifier is applied to the base of the audio amplifier. An incoming signal to the receiver provides noise quieting at the limiters, thereby removing both the noise at the noise amplifier and the positive output from the rectifier.



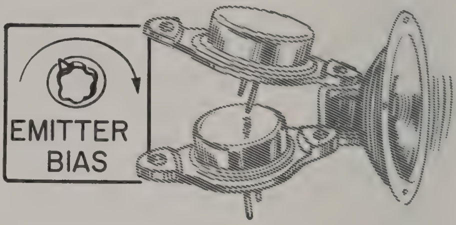
Distortion Can Be Reduced by Connecting a Resistor Between the Collector and Base.

Where the receiver is a part of a complete two-way station, some means is usually employed to disable (mute) the receiver during transmissions. The same idea used to squelch the receiver is employed to mute the receiver during transmission.

The DC return of the noise rectifier is at the lower terminal of CR1 (point A in figure 12), and this connects to the transmitter filament supply line. When the transmitter is turned on, the positive side of the DC supply line to the transmitter filaments is applied, through the diodes, to the base of the audio transistor, thereby reverse biasing the emitter junction and preventing the audio stage from operating. This mutes the receiver during periods of transmission. As soon as this filament voltage is removed, the audio amplifier is again controlled by the squelch circuit.

Transistorized Mobile Receiver Squelch System

Figure 13 shows the block diagram of the squelch system of a completely transistorized mobile receiver. Except for the use of transistors, designated as Q1, Q2, etc., the block diagram is the same as that of vacuum-tube models already studied. Noise from the discriminator is applied to the noise amplifier-limiter, which is followed by a noise rectifier. The DC output of the rectifier controls the operation of the DC control stage which, in turn, controls the operation of the first audio amplifier.



Proper Operation of the "Class B" Push-Pull Audio Amplifier Depends Upon the Correct Emitter Bias.

The noise amplifier operates as any amplifier-limiter. In the absence of a channel signal to provide noise quieting in the receiver, noise voltages are applied to the input and a predetermined amount of noise appears in the output of the amplifier-limiter. This noise is passed on to the noise rectifier.

The noise rectifier--called a "detector" in the complete circuit--provides a DC output voltage from the applied noise. Because there is a filter in the output of the stage which allows only a DC voltage rather than any signal or changing voltage at the output, we can see why this stage serves the same purpose as the noise rectifier of the vacuum-tube squelch circuits we have already studied.

The DC output of the noise rectifier (present without a channel signal being applied) biases the DC control stage so that it is conductive, and when the DC control stage conducts it drives the audio amplifier stage to nonconduction. Any noise voltages in the receiver circuits cannot get through the audio stage to the speaker. Operating in this manner, the squelch circuit of figure 13 controls the receiver output.

When a signal is received, the opposite effect takes place. The noise input to the rectifier from the amplifier has been removed and hence there is no DC output voltage to drive the DC control stage to conduction. When the DC control stage does not conduct, the audio stage is biased normally and the incoming signal reaches the speaker.

We have just seen the over-all operation of the circuit as analyzed from the block diagram of figure 13. We shall now proceed to inspect the circuit in greater detail, beginning with the bias of the audio amplifier.

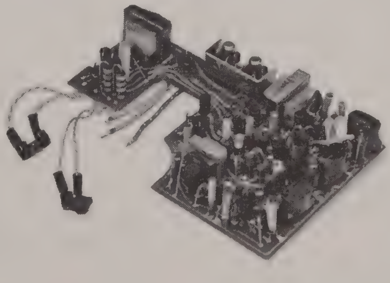
Figure 14 shows how DC control transistor Q3 determines the conduction of the audio amplifier, by altering the emitter bias. When the control transistor is nonconductive it appears as an open circuit, as shown by the open switch. For this condition, the audio amplifier operates in the normal manner and amplifies the incoming signal as desired. When the DC control transistor becomes conductive it acts like a shorted switch in figure 14; it causes the audio amplifier to be reverse biased and nonconductive. Here is what happens.

Resistors R3 and R5 form a voltage divider across the supply and forward bias the emitter junction. Resistor R2 is a stabilizing resistor, producing a voltage drop which opposes the biasing voltage across R3. As we have seen in preceding lessons about transistor bias, the voltage of R3 is normally greater than that of R2 and the emitter junction is forward biased. The incoming signal is amplified and reaches the audio output stages.

When the DC control transistor is conductive (represented in figure 14 by closing the switch) the emitter of the audio transistor is connected to the negative side of the supply line through the switch (emitter-collector section of the transistor).

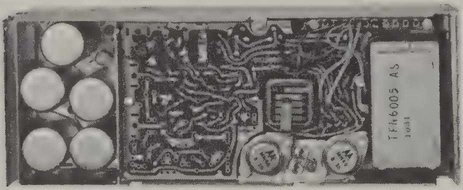
The emitter of Q4 is now negative to the base and the transistor is reverse biased. The transistor is cutoff and noise present in the receiver cannot get through to the speaker.

We have just seen that the operation of the squelch depends upon the conduction or nonconduction of the switch transistor (DC control



Here We See a Typical "Printed Board." This is the Audio and Squelch Section of a Modern Motorola Receiver.

stage). From figure 15 we see that conduction of Q3 may be determined by its base voltage, point C in the figure. If the base is made positive to the emitter, by moving the pot to the bottom of the figure, the transistor is reverse biased and nonconductive. This is the same condition as the open switch shown in figure 14.



This Modern Two-Way Communications Receiver Includes Two Power Transistors (Lower Right). The Cast Aluminum Frame Makes an Efficient Heat Sink.

In order to make the transistor conduct, the pot is moved to the upper end. This forward biases the transistor and allows it to conduct, duplicating the "closed switch" condition of figure 14. Of course, in the final arrangement there is no pot to be moved and perform this function, but this same action happens electrically to the base voltage. See figure 16.

In figure 16 the base voltage is controlled by the operation of the rectifier stage, Q2. The rectifier, in turn, depends upon an incoming signal (noise) for its operation. Without a signal (noise voltage) the transistor does not conduct; when noise is applied the stage acts like a rectifier and conducts on the incoming negative peaks. Let's see how this effects the operation of DC control (switch) transistor Q3.

When the receiver is turned on, capacitor C1 quickly charges to the full supply voltage, through R1. As soon as the capacitor is charged there is no further current through R1 and no voltage across it. The base of Q3, point C in the circuit, is now at the same potential as the positive side of the supply line. The emitter is less positive, however, due to the voltage drop across R2. The DC control transistor is thus reverse biased and is nonconductive; the audio stage may operate normally until something happens to change the voltage at point C, the base of Q3.

When noise is present in the receiver (in the absence of an incoming signal), the negative alternations of the noise pulses from the noise amplifier drive the base of transistor Q2 negative with respect to the emitter and cause the transistor to conduct. This allows a discharge path for capacitor C1 through the transistor and, at the same time, emitter current through R1 causes the base of Q3 (point C) to swing negative. The base is driven negative with respect to the emitter and transistor Q3 conducts, thereby reverse biasing the audio amplifier and squelching the receiver.

As long as noise voltage is applied to the noise rectifier, the base of the DC control transistor remains negative to the emitter and the squelch remains closed. As soon as the noise input is removed from the rectifier, however, the rectifier no longer con-

ducts and capacitor C1 charges to the supply voltage once more, cutting off the DC control stage and allowing the squelch to open. This is desirable, however, for we know that when the noise is removed there is a signal coming into the receiver and the squelch should be open so that the message may reach the speaker.

We have just seen the basic principles of the transistorized squelch circuit. The only stage which we have not analyzed in detail is the amplifier-limiter, and this operates in exactly the same manner as the vacuum-tube amplifier-limiter in other receivers. By having a certain predetermined maximum output voltage regardless of the nature of the incoming signal, the noise rectifier has a relatively constant noise voltage applied when there is no signal. The limiting function of the stage serves to avoid clamping of the squelch in the presence of weak or over-modulated signals. Clamping is covered in the previously mentioned squelch lesson.

The complete circuit of this squelch system is given in figure 17. Although there are more component parts in the various stages compared to the simplified circuits we have been discussing, the operation of each stage is still the same; these added parts assure stable, positive operation.

In the biasing circuit for the base of audio transistor Q4, we see four resistors in series. One of these, R6, is a Varistor and is sensitive to changes of voltage. In fact, this resistor changes its resistance with changes of applied voltage and in this manner maintains constant bias voltages and operation of the stage.

There is a DC filter in the base circuit of the DC control stage which provides a steady DC voltage from the rectified noise pulses at the rectifier output. The time constant of this filter is sufficiently long to prevent the voltage from varying with sudden changes of input signal.

In order to prevent the squelch circuit from clamping, some upper-frequency voice energy is introduced into the amplifier-limiter. The input to the squelch circuit from the discriminator is taken ahead of the deemphasis filter and higher voice frequencies have a higher than normal amplitude. These voice signals overdrive the limiter and block it as far as noise signals getting through are concerned. Thus, the output of the noise amplifier-limiter is nearly free from noise energy when voice modulation is present; as a result, very little noise reaches the rectifier. The squelch cannot clamp in the presence of a modulated signal, for the noise level at the squelch cannot increase during modulation.

Although voice energy is desirable in the amplifier stage, in order to prevent clamping, it is equally as undesirable for this voice energy to reach the noise rectifier and produce an output voltage, for this would cause clamping. The coupling circuit between the amplifier and the rectifier, the "peaking coil" L1 in particular, attenuates the low-frequency voice signals and prevents them from reaching the rectifier.

This concludes our discussion of low-frequency applications of transistors. In our next lesson we will deal with high-frequency circuits.

STUDENT NOTES

STUDENT NOTES

STUDENT NOTES

CIRCUIT	INPUT Z	OUTPUT Z	Z GAIN	VOLTAGE AMPL.	POWER GAIN	CURRENT GAIN		PHASE	EQUIV. TUBE CIRCUIT
COMMON EMITTER	MEDIUM	MEDIUM HIGH	MEDIUM	HIGH	HIGH	HIGH	HIGH	YES	GROUNDED CATHODE
COMMON BASE	MEDIUM LOW	HIGH	HIGH	HIGH	MEDIUM	NONE	MEDIUM	NO	GROUNDED GRID
COMMON COLLECTOR	HIGH	MEDIUM LOW	(LOSS)	NONE	LOW	HIGH	LOW	NO	CATHODE FOLLOWER

FIGURE 1

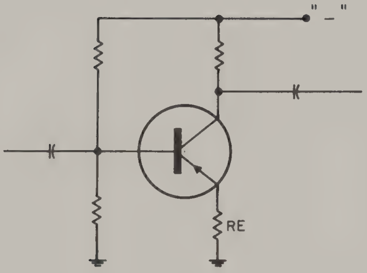


FIGURE 2

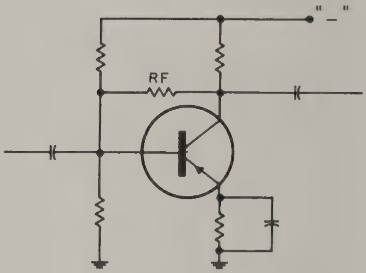
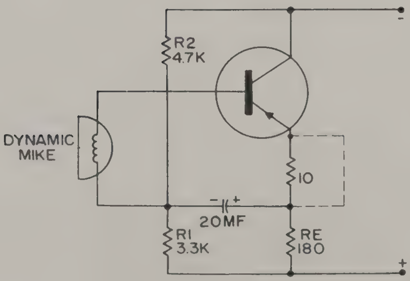
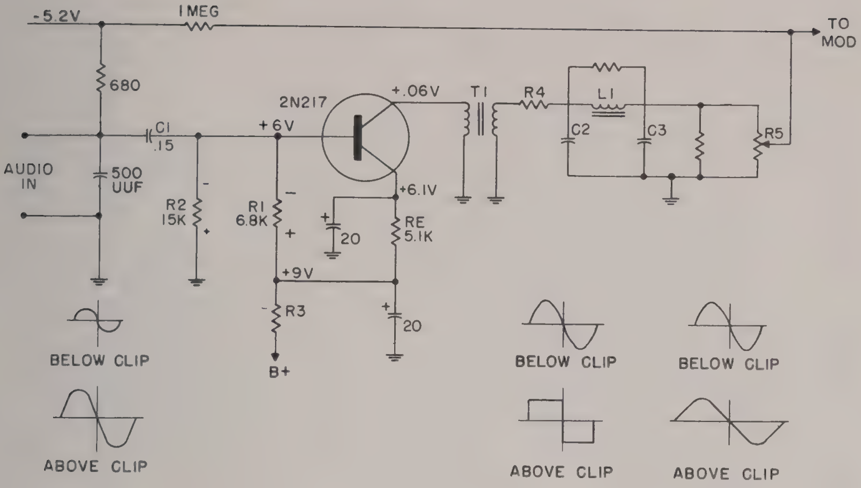


FIGURE 3



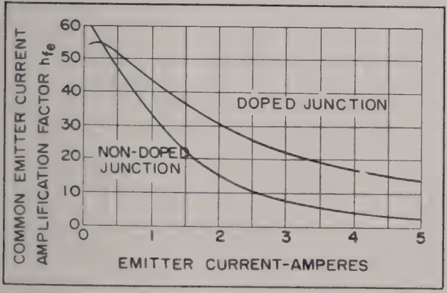
MICROPHONE PREAMPLIFIER

FIGURE 4

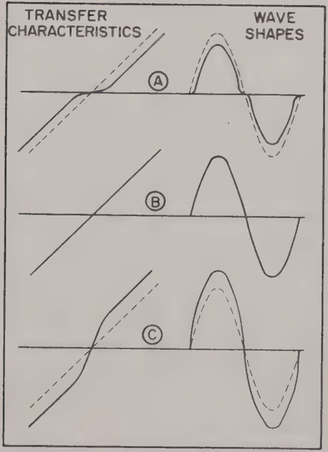


PORTABLE
IDC CIRCUIT

FIGURE 5



COMMON EMITTER CURRENT
AMPLICATION FACTOR vs EMITTER CURRENT
FIGURE 6



CLASS "B" AMPLIFIER
CROSS-OVER DISTORTION
FIGURE 7

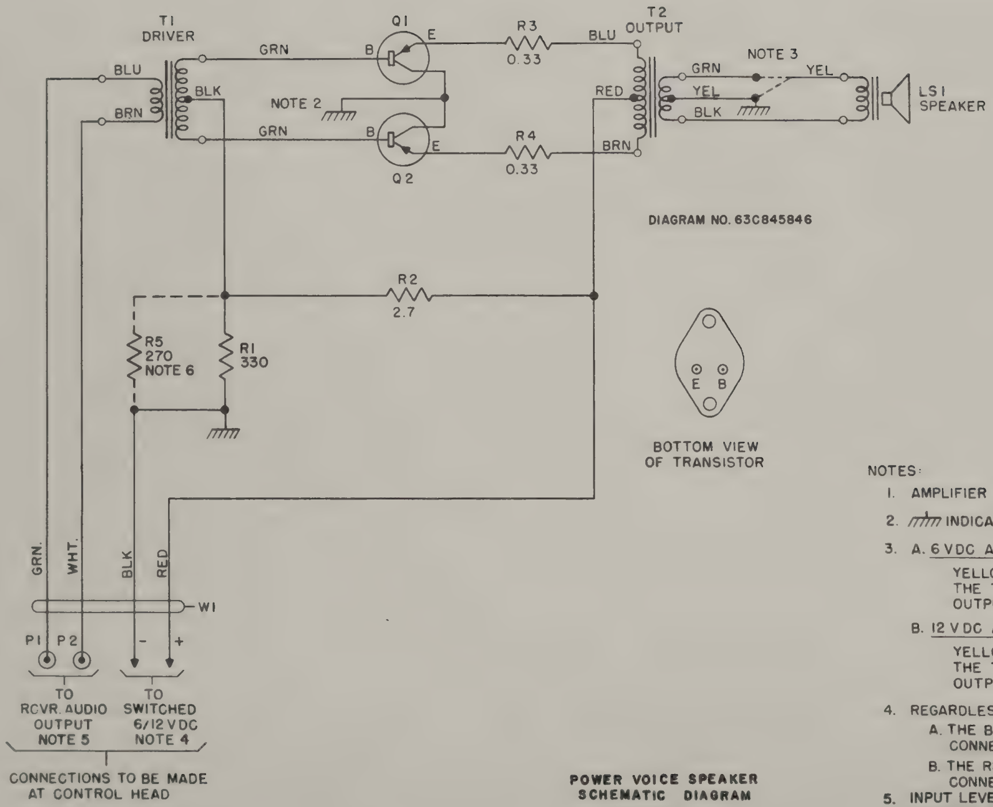


DIAGRAM NO. 63C845846

BOTTOM VIEW
OF TRANSISTOR

NOTES:

1. AMPLIFIER CHASSIS IS INSULATED FROM HOUSING.
2. ⏚ INDICATES CONNECTION TO AMPLIFIER CHASSIS.
3. A. 6 VDC APPLICATIONS (TU 433A-6V):
   YELLOW SPEAKER LEAD IS CONNECTED TO THE TIE-POINT OF THE GREEN LEAD OF OUTPUT TRANSFORMER T2.

   B. 12 VDC APPLICATIONS (TU 433A-12V):
   YELLOW SPEAKER LEAD IS CONNECTED TO THE TIE-POINT OF THE YELLOW LEAD OF OUTPUT TRANSFORMER T2.
4. REGARDLESS OF VEHICLE GROUND POLARITY:
   A. THE BLACK LEAD OF CABLE W1 MUST ALWAYS CONNECT TO NEGATIVE (-) SIDE OF BATTERY.
   B. THE RED LEAD OF CABLE W1 MUST ALWAYS CONNECT TO POSITIVE (+) SIDE OF BATTERY.
5. INPUT LEVEL NOT TO EXCEED 1W AT 1000 CPS.
6. RESISTOR R5 IS USED ONLY IN 6VOLT MODEL.

**POWER VOICE SPEAKER
SCHEMATIC DIAGRAM
FIGURE 8**

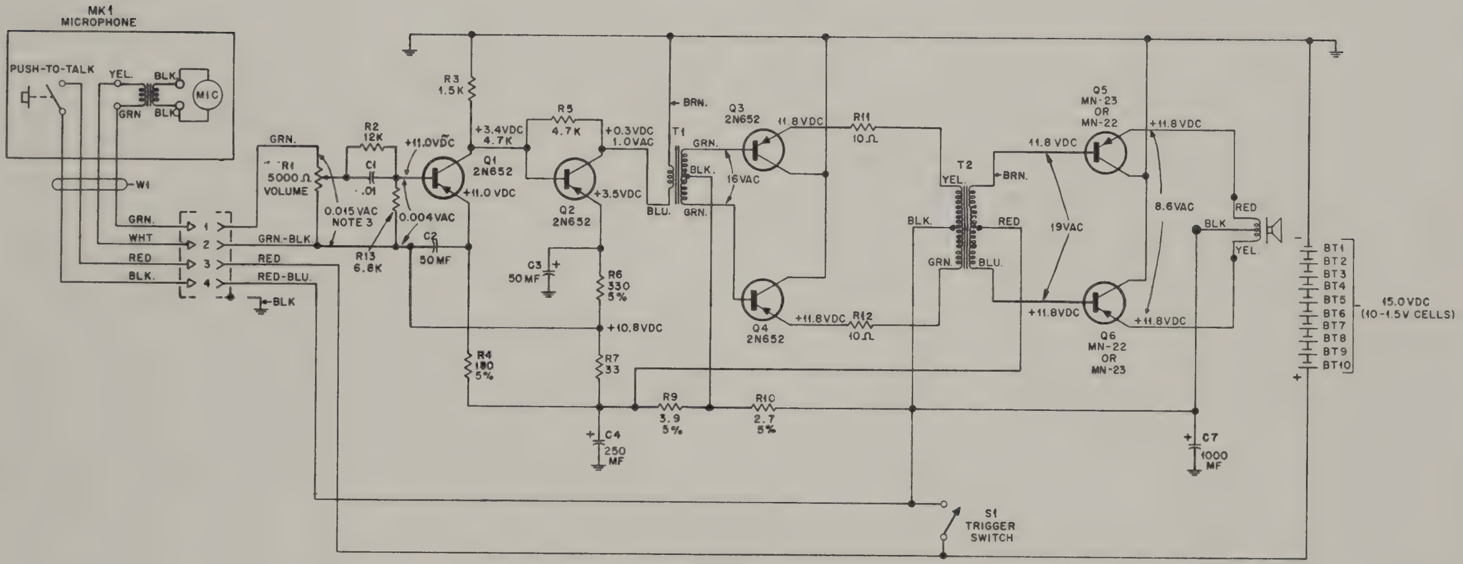
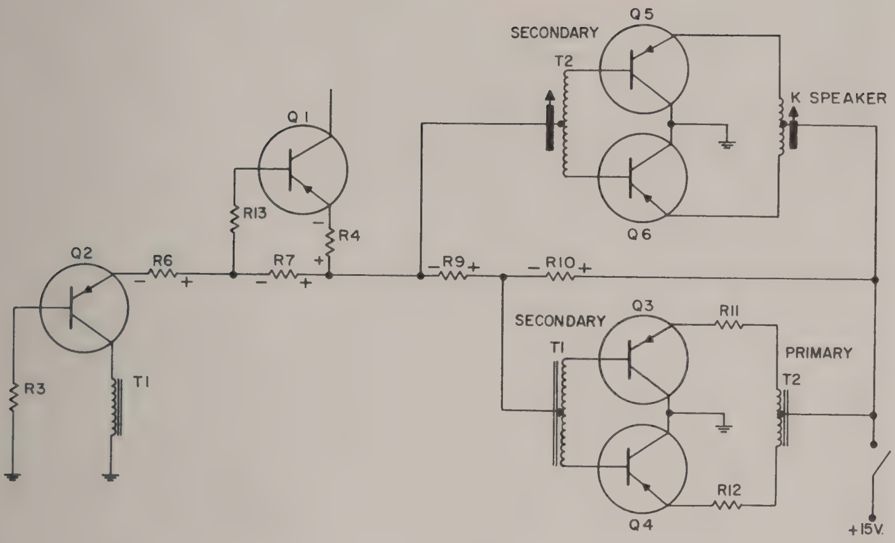


FIGURE 9

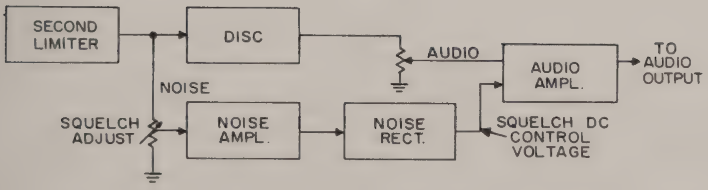
NOTES:

1. ALL VOLTAGE READINGS TAKEN USING A 12VDC SUPPLY.
2. DC VOLTAGES MEASURED TO GROUND WITH ZERO (0) SIGNAL INPUT.
3. AC VOLTAGE MEASURED ACROSS POINTS INDICATED BY ARROWS.
4. ALL OTHER AC VOLTAGES MEASURED FROM GROUND.
5. ALL AC VOLTAGE READINGS MEASURED WITH A 15 MV 1000 CPS SIGNAL CONNECTED ACROSS THE VOLUME CONTROL (SET TO MAXIMUM) AND SPEAKER REPLACED WITH DUMMY LOAD WITH 8.6V ACROSS LOAD. (SEE TEXT)
6. ALL RESISTORS 1/2W ± 10% UNLESS NOTED.



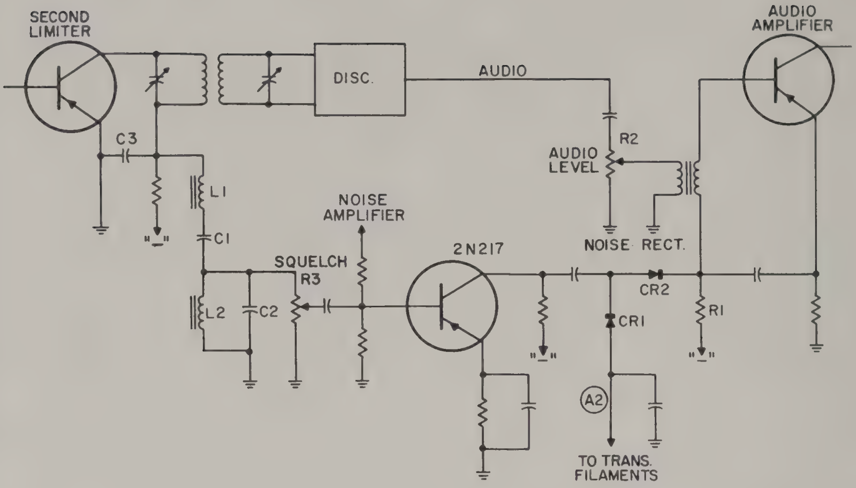
BIAS CIRCUIT
POWER VOICE MEGAPHONE

FIGURE 10

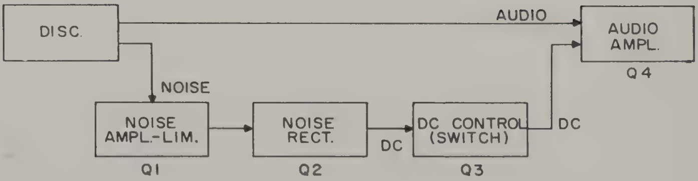


SQUELCH CIRCUIT OF
PORTABLE RECEIVER

FIGURE 11



SQUELCH CIRCUIT
FIGURE 12



MOBILE RECEIVER
TRANSISTORIZED SQUELCH

FIGURE 13

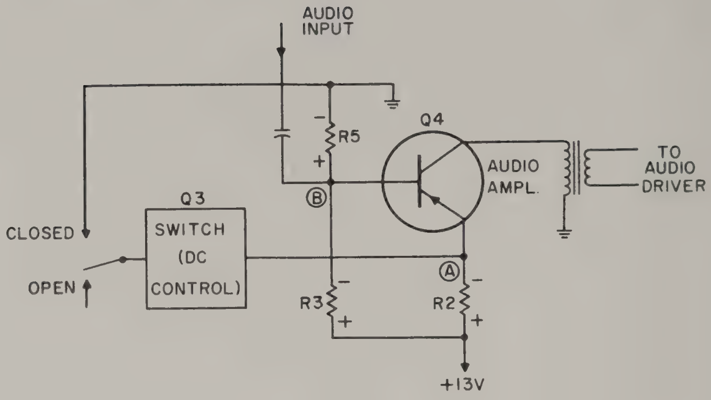


FIGURE 14

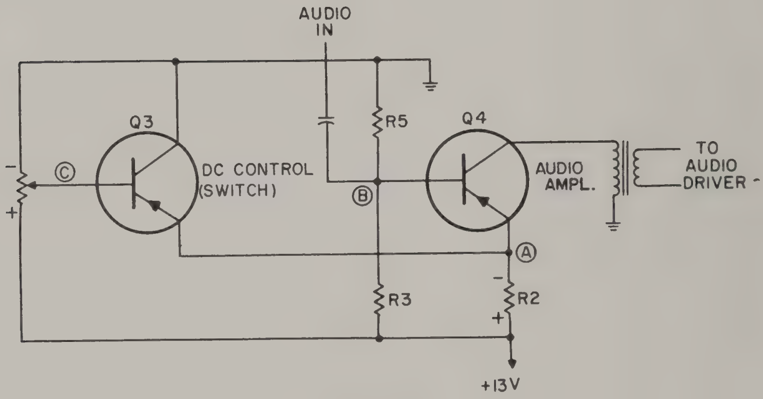


FIGURE 15

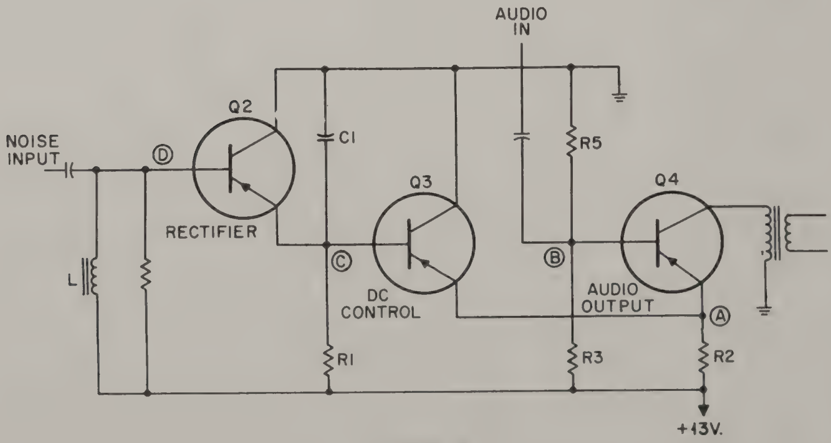
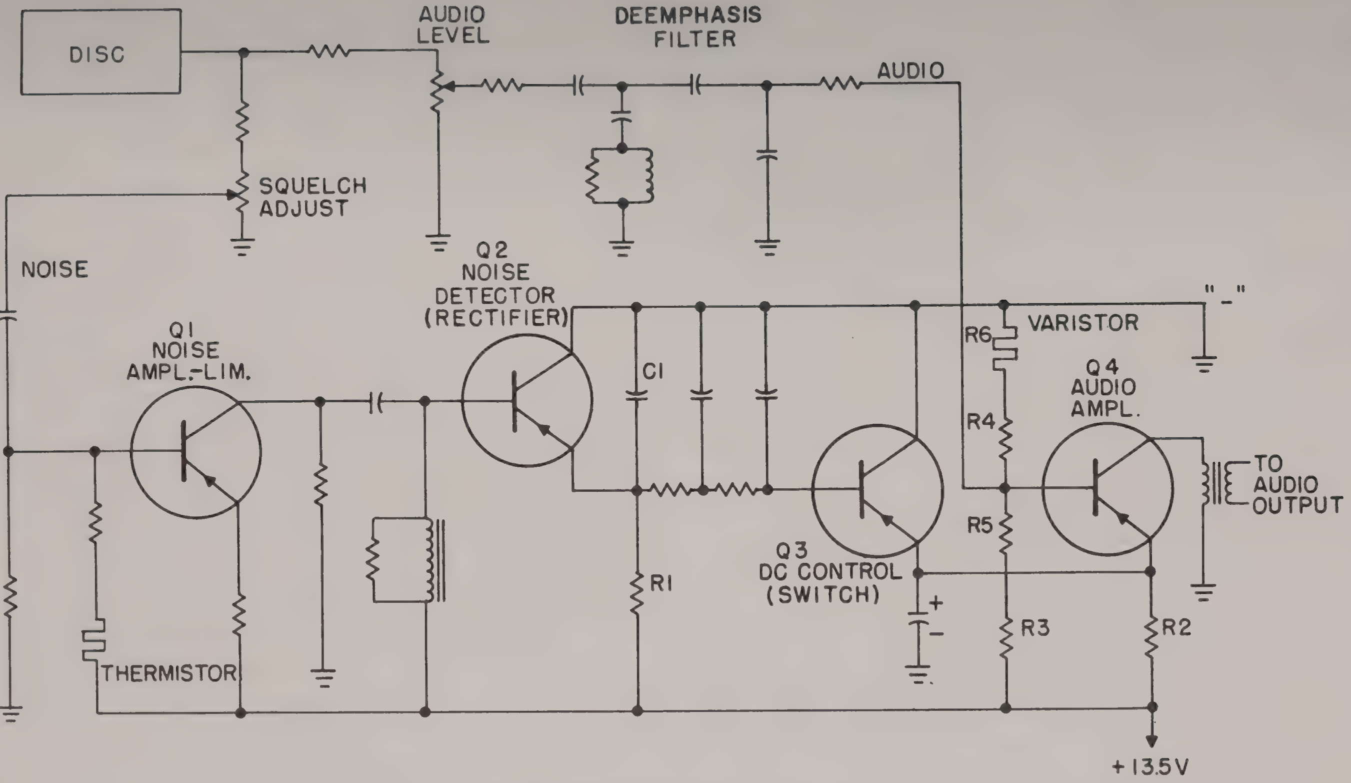


FIGURE 16



COMPLETE SQUELCH CIRCUIT

FIGURE 17

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Name ______________________________ Student No. ______

Street ____________________ Zone ____ Date _______

City _______________ State ________ Grade ______

EXAMINATION, LESSON SA-6

1. The (common-emitter) (common-base) (common-collector) circuit gives the greatest power gain. The (common-emitter) (common-base) (common-collector) is used where the source impedance is very low and the load impedance is high. The (common-emitter) (common-base) (common-collector) circuit is best used where a high input impedance and a low output impedance is desired.

2. Write "transformer coupling" or "RC coupling" by each of the following, whichever applies.
   ______________ Allows maximum gain.
   ______________ Is the most compact.
   ______________ Is the most economical.
   ______________ Is used for large signals.

3. Figures A and B show two circuits having DC temperature stabilization. Which of these two also has degenerative feedback due to this stabilization?
   A ___________ B. ___________

4. Power transistors have two inherent factors which are undesirable when encountered in amplifiers; (1) the current amplification remains constant even though the emitter current increases, and (2) the input impedance is not linear.
   TRUE______ FALSE______

5. Doped power transistors, in which a small amount of gallium has been added to the emitter junction, have a more constant gain for changes of emitter current. Only a slight increase in gain is noted at the higher current values. TRUE____ FALSE___

6. Power transistors operating in Class A conduct current continuously, independently of a signal being applied, and thus produce internal heat at all times. Class B push-pull transistor stages are biased close to cutoff and thus conduct very little current unless a signal is applied. TRUE______ FALSE

7. The initial bias of push-pull Class B transistor stages is very important to the reduction of distortion. This operating point must be kept constant at all times for good operation. TRUE______ FALSE______. The emitter resistor used for voltage stabilization must be bypassed for proper operation. TRUE______ FALSE______.

8. In order to provide for good heat dissipation of power transistors, it is customary to use a "heat sink" or a good chassis connection to carry the heat away from the transistor and thus reduce the operating temperature. TRUE______ FALSE______

9. If the ambient temperature is the maximum allowed, any current through power transistors will heat the units beyond the safe amount and cause trouble. TRUE______ FALSE______

10. One of the major advantages in operating power transistors in Class B push-pull is the low standby current when there is no output. Biased near cutoff, the current through the transistors is small and there is little heat developed. This also lowers the average amount of current taken from the supply. TRUE______ FALSE______.

FIGURE A

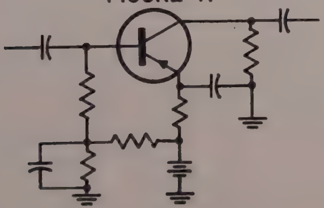
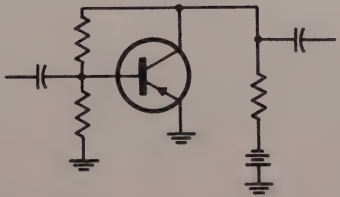


FIGURE B



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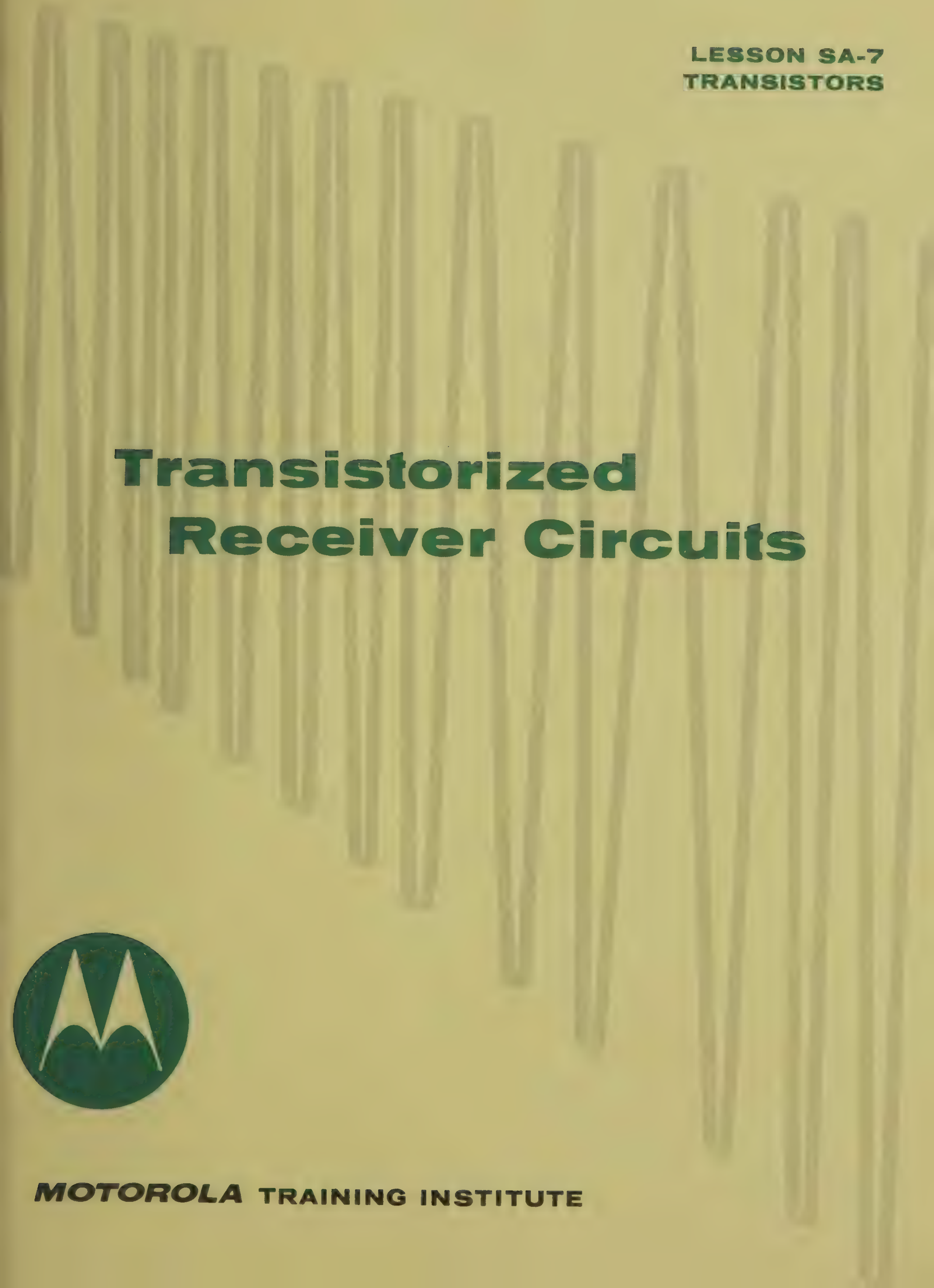
A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON SA-7
TRANSISTORS

Transistorized Receiver Circuits



MOTOROLA TRAINING INSTITUTE

A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON SA-7
TRANSISTORS

Transistorized Receiver Circuits

—one of a series of lessons on two-way FM communications—

MOTOROLA TRAINING INSTITUTE
4501 W. AUGUSTA BLVD., CHICAGO 51, ILLINOIS
APPROVED BY THE STATE OF ILLINOIS
DEPT. OF REGISTRATION AND EDUCATION

PREFACE

This is one lesson of a complete Motorola Home-Study Course which presents to the Service Technician both the principles of operation and the maintenance of two-way FM radio systems. The program covers mobile, portable and base station equipment, including the latest transistorized units.

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TRANSISTORIZED RECEIVER CIRCUITS

LESSON SA-7

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FREQUENCY MULTIPLIER. . . . . .Page 21
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NOTICE

Diagrams and figures referenced in text are "fold-outs" in back of each lesson, for use while studying. The Examinations are also there.

Extensively transistorized two-way units are ideally adapted for use on personnel carriers and other small plant area vehicles. Compactness, reliability, and low battery drain are basic requirements for this application.

TRANSISTORIZED RECEIVER CIRCUITS

Lesson SA-7

Introduction

This lesson is basically a discussion of transistors applied to high-frequency circuits. At the beginning, transistors were restricted to audio and other low-frequency circuits by their inability to amplify at higher frequencies. With improved transistor construction and manufacturing techniques, however, transistorized broadcast-band receivers and other higher frequency equipment became possible. These improved transistors allowed for the transistorization of the last IF section, the squelch section and the audio stages of the communications receiver, such as the Motorola Handie-Talkie two-way portable radio.

Further advances in transistors for high-frequency amplification and operation finally allowed for practical, completely-transistorized two-way radios capable of operating in both the high and low bands.

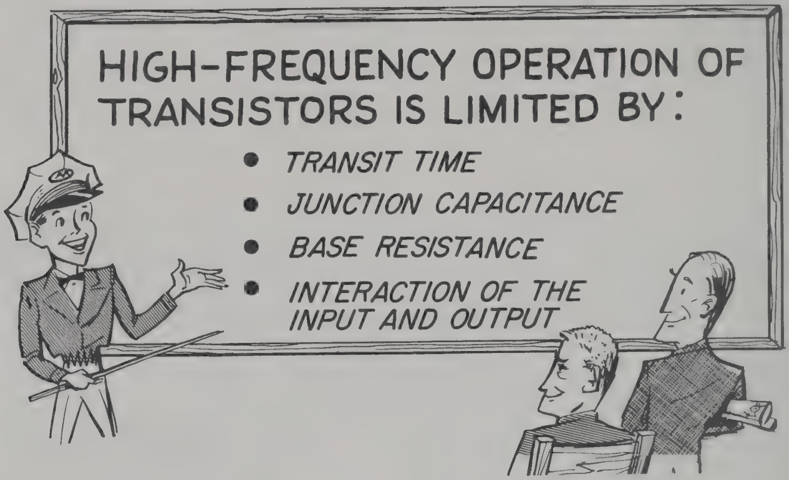
In this lesson we will see the circuitry of the various stages within these receivers. The transistors for these circuits are low-power units, generally falling below the 100 milliwatt rating. It is only when the signal reaches the audio output section of the receiver that transistors capable of more power are required.

High-Frequency Limitations of Transistors

The general purpose, low-power transistor used in low-level audio stages is not suitable for the high-frequencies section of the receiver. These are several reasons why these transistors cannot amplify at high frequencies.

One of the main limitations of high-frequency operation is the time it takes for the carriers to cross the base region, between the emitter and the collector junctions. At higher frequencies less time is required for a complete cycle; if this time period becomes so small that the transit time of the carriers is an appreciable part of the cycle, the amplifier becomes degenerative and is incapable of providing much gain.

Another reason for the high-frequency failure of some transistors is the capacitance of the junctions, particularly that between the collector and base. This


HIGH-FREQUENCY OPERATION OF TRANSISTORS IS LIMITED BY:
• TRANSIT TIME
• JUNCTION CAPACITANCE
• BASE RESISTANCE
• INTERACTION OF THE INPUT AND OUTPUT

Only a Few Types of Specially Designed and Carefully Built Transistors Will Operate Satisfactorily at High Frequencies.

is usually referred to as the output capacitance. At high frequencies the capacitive reactance at this junction becomes so low that the signal is effectively shorted and it is impossible to develop any signal voltage or power across the output load.

Still another reason for the high-frequency limitation of many transistors as an amplifier is the base resistance. A high resistance makes it difficult to establish much signal current, thereby limiting the gain.

The interaction between the input and the output of the transistor also limits the gain of transistors at high frequencies. Although there is some interaction between the input and output in vacuum tubes, this effect is considerably greater in the transistor.

The degree to which the above limiting factors are controlled or minimized determines the cutoff frequency of the various types of transistors. We shall now discuss briefly various transistor designs in view of these limiting factors.

Alloy-Junction Transistors

The construction of the alloy-junction transistor is illustrated in figure 1. The base is made from a relatively large wafer of N-type material. (An NPN transistor can also be constructed by using a P material for the base.) The collector and emitter junctions are made by placing small pellets of P-type material on opposing sides of the base and heating the assembly until the P material alloys into the base region. The P material penetrates into the N base material, becoming the emitter and collector. By carefully controlling the process, the depth of penetration is regulated and the emitter and collector junctions may be as close as 0.0005 inch.

With an extremely small distance between the emitter and collector, the alloy-junction transistor has a short transit time and is capable of operating at higher frequencies. By utilizing large contact areas to the base, and spaced close to the emitter, the resistance between the emitter and base is kept low and contributes to the ability of the unit to provide high gain. In addition, by using small pellets, the capacitance of the emitter and collector to the base is kept reasonably small and does not prohibit high-frequency operation.

Alloy-junction transistors have an alpha cutoff frequency as high as 25 mc. The corresponding beta cutoff, for a common-emitter circuit, will be around 1 mc. The cutoff frequency indicates the frequency at which the gain has lowered 3 db below the gain at low frequencies. A 3-db decrease is a two-to-one reduction in power output.

Diffused-Base Transistors

The basic idea of diffused-base transistors is to establish an internal field across the base region which accelerates the carriers, thereby reducing the time it takes for the carriers to travel from the emitter to the collector. This is achieved by varying the conductivity of the base region, which, in turn, is made possible by altering the concentration of the impurity atoms in the base material. See figure 2.

The base material of diffused-base transistors is doped so that there is a strong concentration of impurity atoms near the emitter junction and a gradual decrease of impurity atoms toward the collector. This is shown in the figure by the number of vertical lines within the base. Thus, the portion of the base nearest the emitter is a high-conductivity region whereas the area near the collector is a low-conductivity area.

The overall effect is to create a field which sweeps the carriers, moving from the emitter into the base, toward the collector. This reduces the time it would otherwise take for the carriers to cross the base region. A short transit time, reduced to one-fourth or less the normal value, means that the transistor is capable of amplification at considerably higher frequencies. Transistors of this type have been built with cutoff frequencies in excess of 200 mc.

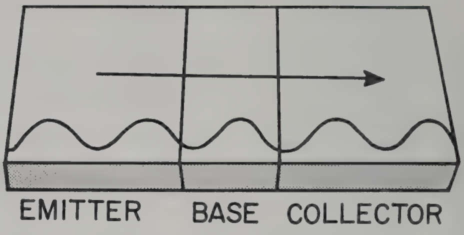
In addition to the improvement in transit time, the high frequency performance of diffused-base transistors is further improved by a reduction in input resistance. With a higher concentration of impurities near the emitter, the input resistance is also less and allows for higher gain. Also, low conductivity in the base area near the collector means that the effective capacitance at the output junction is less (there is less voltage drop at the junction).

These conditions all help to improve the ability of the transistor to provide gain, and most high-frequency transistors now in use utilize some form of impurity gradient in the base. Transistors of this general construction are classed as "diffused-base" transistors.

Surface-Barrier Transistors

Another transistor designed for high-frequency operation is the surface-barrier type. Constructed in somewhat the same manner as the alloy junction unit, the surface barrier gains its high-frequency capabilities from its small size. See figure 3.

Rather than alloying small beads of impurity metal into the base material, surface-barrier transistors are made by electrochemically etching two wells into opposite sides of the base material. These wells are then plated with a material which forms the emitter and collector. This process can be controlled so that the thickness of the base between the emitter and collector is but a few tenths of a mil. This means a very small transit time and good high-frequency characteristics.



Where the Transit Time of the Carriers Through the Base is an Appreciable Portion of One Cycle, the Transistor Will Not Provide Much Gain.

Units of this type have been made with cutoff frequencies around 100 mc.

In more recent developments, the microetching techniques used in the making of surface-barrier units have been applied to the diffused-base transistor, producing microalloy diffused transistors (m.a.d.t.) capable of amplification and operation at vhf frequencies.

Tetrode Transistors

As indicated by its name, we may anticipate that the tetrode transistor has an additional terminal other than the usual emitter, base and collector. Although there are only three active elements in the tetrode, another connection is made to the base, on the side opposite the normal base connection, and a bias voltage is applied between these base connections. See the sketch in figure 4.

The bias voltages applied to the emitter and collector in respect to the base are the same for triode units we have been discussing, but another DC voltage is applied to the transistor base, between the newly-added terminal and the regular base terminal. The extra biasing voltage across the base connections is normally of the same polarity but larger than that applied to the emitter.

An NPN tetrode is shown, and for this unit the voltage to the fourth terminal must be negative. This means that an electric field is established across the base material as a result of this additional voltage, and the field causes the electrons (the carriers moving into the base from the emitter) to follow a narrow, restricted path through the base region as shown in figure 4.

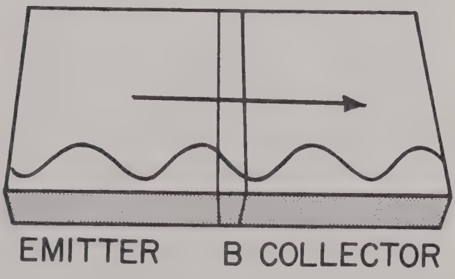
As a result of the narrowed current path, the high-frequency capabilities of the tetrode is improved over the conventional triode. This is due to two factors. First, with a narrower current path the effective capacitance at both the input and output are reduced, allowing for high-frequency operation. Second, the input resistance is reduced because of the shorter path of the emitter-base current. Due to the limited path for current, the power capability of the tetrode is poor; however, this is of no consequence for the requirements of most high-frequency circuits.

Tetrodes in use today are NPN units of the grown type. The two symbols which represent tetrode transistors are shown in figure 4. The upper symbol is the one most often used.

"Mesa" Transistors

An entirely new approach to transistor design has been found. Due to their construction, these units have been labeled "Mesa" transistors; the word "mesa" comes from the Spanish and means "table," and this designation can be understood from the construction of the transistor. See figure 5.

The base is a diffused N region, with an alloyed gold contact. The emitter contact is made by evaporation and alloying, which provides for close control of the important parameters even under mass-production procedures. The collector area is large and has a collector junction which is made from germanium without the presence of any alloy.



A Narrow Base Area Means a Short Transit Time and the Ability to Amplify at Higher Frequencies.

There are many factors which makes this transistor useful at high frequencies. The input resistance of the Mesa transistor is very low and provides a high power gain, particularly at higher frequencies.

The spacing of the emitter and collector is also kept to a minimum and is readily controlled. This also enhances the high-frequency operation. The diffused base reduces the transit time in the base region and also lowers the effective output capacitance. In addition, the features of the mesa transistor indicate that it may be capable of both high-frequency and high-power applications.

At the start, almost all the mesa transistors produced were used by the military and other government services, but units have since been released and are in use in two-way radio communications equipment.

We have just seen the construction of those transistors which seem to be the best suited for two-way communications equipment. Thus far two major advances have occurred as far as transistorized receivers are concerned. The first occurred some time ago when transistorized 455-kc IF amplifiers became possible. This allowed for the major portion of the receiver to use transistors, with only the RF, oscillators and first IF section using vacuum tubes.

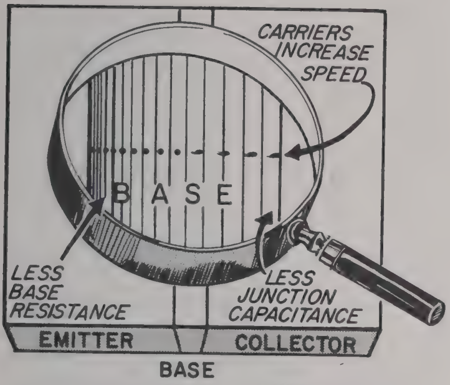
The Handie-Talkie radiophone was the first application of this type, and the basic unit is still in use. In addition to its service as a light portable unit, this receiver has been modified and adapted to provide a low-drain unit for motorcycles and similar vehicles.

The second and equally important break-through in transistor design was the introduction of VHF transistors which could be incorporated into mass-produced, mobile two-way radios. All the stages of the receiver could now be transistorized; this does away with the high-voltage supply, for all the stages operate from the low-voltage primary source. In addition, there are no tube filaments to heat, so that both the standby and the operating currents for the receiver are very small.

In the remainder of this lesson we shall see the use of transistors in the various receiver circuits. Before we start with the IF and RF sections, however, we shall discuss the various methods of coupling high-frequency stages.

IF and RF Coupling Methods

Coupling in either the IF or RF sections of a receiver must take several basic factors into consideration. First, an impedance match must be provided for the input and output circuits if maximum power gain is to be realized. Second, the selectivity achieved by the tuned circuits must be in conformity with the requirements of the receiver at that point.



DIFFUSED BASE TRANSISTOR

The Diffused-Base Technique is Used Almost Universally in High-Frequency Transistors.

For example, a tuned coupling section may provide too little selectivity, in which case undesired signals get through the receiver along with the desired. Or, it may be too selective, in which case the side-band energy of the desired signal does not reach the detector. Thus, it is important to consider the selectivity of tuned coupling circuits as well as the impedances.

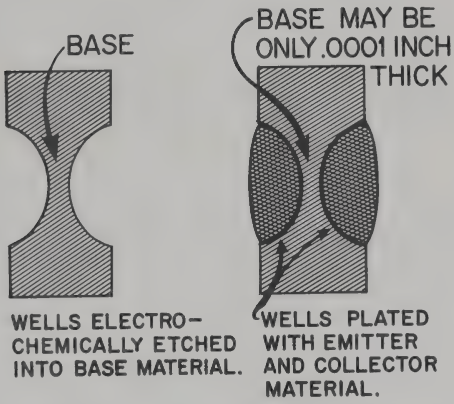
Transistors are quite different from vacuum tubes in the amount of impedance presented at both their input and output. While the output impedance of a transistor may be several thousand ohms for some applications, at high frequencies it will probably be considerably lower. The input impedance to a transistor stage is considerably less than its vacuum-tube counterpart, often being lower than 100 ohms.

When we realize that these input and output impedances of the transistor stage load the tuned circuits with which they are associated, we can readily see why a tuned circuit arrangement which provides a satisfactory amount of selectivity for a vacuum tube stage may not be at all useful for the transistorized amplifier.

When considering coupling systems for transistor stages, it is normal to expect that the input to the coupling element has a higher impedance than the output. This is another way of saying that the output impedance of the transistor stage is normally higher than the input of the next stage. With these factors in mind we are ready to inspect some tuned coupling circuits.

In figure 6 we see a transformer with a tuned primary and an untuned secondary. With the primary circuit tuned and with a relatively few turns in the secondary winding, the primary impedance will be considerably higher than that of the secondary. The secondary is close-coupled to the primary, so that in effect the secondary acts like a tap on the primary, as in figure 7. This, then, is one possible method of coupling from the output of one amplifier stage to the input of another.

Figure 7 shows another means of coupling transistor stages with one tune circuit. Here a tap on the coil of the tuned circuit provides a point of low impedance, and this tap may be the input to the second stage as shown. In order to prevent interaction of the DC bias voltages, a series DC blocking capacitor is included.


BASE
BASE MAY BE ONLY .0001 INCH THICK
WELLS ELECTRO-CHEMICALLY ETCHED INTO BASE MATERIAL.
WELLS PLATED WITH EMITTER AND COLLECTOR MATERIAL.

SURFACE BARRIER TRANSISTOR

The Surface-Barrier Transistor is a Means of Securing an Extremely Thin Base Region.

At high frequencies where the coil has but a few turns, it is sometimes difficult to secure the desired impedance at the tap, for the impedance of the tap varies with the "square" of the turns rather than directly with the turns. In addition, where the coil is the tuning element, changing the position of the tuning slug in the coil changes the relative impedances, and thus the impedance ratio. This disrupts the impedance match between the stages.

In figure 8, we see an alternate method of providing the desired impedances with one tuned circuit. Instead of a tap on the coil, two capacitors are placed in series with each other to form the "C" of the tuned circuit, and the "tap" is the midpoint of the capacitors. The impedance of this tap varies according to the reactance of the capacitors, and this is controlled directly by the capacitance of the individual units. Furthermore, the coil may now be tuned without upsetting the impedance ratio of the circuit. The series-connected, DC-blocking capacitor of figure 7 is not needed for this arrangement.

The preceding examples of coupling with but one tuned circuit assume that the loading of the output of the stage upon the tuned circuit does not lower the Q so much as to prevent the desired selectivity. Where the output of a transistor cannot be connected directly to the top of the tuned circuit because of this loading effect, it is permissible to use a tap on the tuned circuit the same as is done for the secondary. See figure 9.

In figure 9 both the input and output connections are provided by taps on the coil. It is possible that either or both of these could be secured by the two capacitors as shown in figure 8.

Combinations of the coupling methods already discussed may also be used. For example, the primary could be connected to a tap on a tuned circuit, with a low-impedance, untuned secondary leading to the input of the next stage. Other combinations are also possible.

Where the required selectivity is greater than can be realized by one tuned circuit, a transformer with both the primary and secondary tuned to the desired frequency may be necessary. Furthermore, the degree of coupling between the two circuits can be adjusted to give the necessary selectivity, see figure 10.

Although many broadcast receivers and other low-frequency equipment make use of inductively-coupled transformer (shown in figure 11A), in high-frequency receivers it is common to find the individual tuned circuits capacitively coupled, (shown in figure 11B). At high frequencies the degree of coupling can be readily controlled by capacitive coupling, particularly where more than two tuned circuits are used.[1]

The 455-KC Amplifier

Having discussed various possible coupling methods for IF and RF stages, we are ready to look at some specific examples. Because it was the first to be used in two-way communications, we shall start with the low-IF section of the Handie-Talkie.

Figure 12 shows the simplified IF amplifier circuit using a PNP transistor in a common-emitter circuit. The positive terminal of a 4-volt supply is grounded, so the emitter is effectively connected to the positive side of the supply. The forward bias on the emitter junction is provided by the voltage divider (R1 and R2), the voltage across R2 making the base negative with respect to ground (emitter).

As soon as the transistor conducts, the voltage drop across R3 makes the emitter also negative with respect to ground. Since both the base and emitter are negative, the forward bias is the difference between the two potentials, or 0.2 volt. The reverse bias of the collector junction is 3.3 volts, the difference between the negative potentials of the collector and base.

DC stability for temperature changes is provided by resistor R3 in the emitter circuit. The operation of this circuit has been analyzed in preceding lessons. The bypass capacitor parallel to R3 prevents degeneration.

In figure 12, the output is coupled to the next stage by means of a coupling capacitor. This capacitor is in series with the input impedance (capacitance) of the next stage and together they form part of the tuned circuit, for, as far as AC is concerned, they are in parallel with the tuning coil. The coupling capacitor is considerably smaller than the input capacitance of the next stage, so its impedance is high compared with the impedance of the input. This circuit is thus similar to the arrangement of figure 8.

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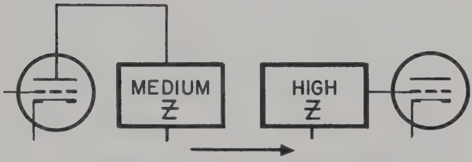
1. See Basic Theory and Application of Transistors (TM11-690), pages 144-151.

Neutralizing the IF Amplifier

Due to regeneration in the 455-kc amplifier, it is often necessary to include neutralization for stable, high-gain amplification. Any system of neutralization which can be used with vacuum tubes applies equally well to transistor amplifiers. Figure 13 illustrates the neutralization system of the IF circuit of the Handie-Talkie. Figure 13A shows the path of the undesirable feedback voltage, from the output through the transistor to the input circuit. In a transistor, this feedback is considerable and it must be counteracted.



STEP-UP IN IMPEDANCE

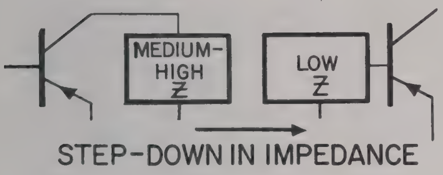
Inter-Stage Coupling Methods in Vacuum-Tube Equipment Must Provide an Impedance Step-Up From One Stage to the Next.

Figure 13B shows the method of securing a neutralizing voltage from the output. When applied back to the input, this additional voltage opposes the internal feedback voltage so that the only effective voltage at the input is the original signal from the preceding stage.

The tuned circuit in figure 13B is "tapped" so that the bottom of the tank is no longer at ground potential. Instead, the tap places the ground at some point between the two ends of the coil. With the ground as reference, the upper and lower ends of the coil (points A and B respectively) are now 180° out of phase with each other.

Point A is the source of the feedback voltage through the transistor; point B is the source of the neutralizing voltage, which is fed to the input through neutralizing capacitor Cn. Since the two voltages reaching the input from the output are 180° out of phase, they will completely cancel each other as far as the input circuit is concerned if they are of equal amplitude; the only effective voltage at the input is that applied from the preceding stage.

In figure 13B the coil is grounded, making it impossible to apply the DC voltage to the collector through the coil. This problem is solved by the alternate system shown in figure 12C. Here the tuned circuit is grounded at the midpoint of two series-connected capacitors. Grounding this point does not affect the DC through the coil. At the same time, a ground point is established for the tuned circuit. The relative position of this tap depends upon the reactances of the two capacitors. The opposite ends of the tank, points A and B, are still 180° out of phase and they become the source of the two voltages fed to the input.



Inter-Stage Coupling Methods in Transistorized Equipment Usually Encounter an Impedance Step-Down to the Second Stage.

Figure 14 shows the complete circuit of the IF amplifier stage. C_O is not an individual circuit component or part, but represents the output capacitance of the transistor and circuit. As far as AC is concerned, the reactance of C1 is so small that we should think of C_O as being connected directly between the collector and ground.

The tap on the tuned circuit, required to establish a neutralizing voltage, is provided by the ground connection between C1 and C2. Considering C1 to be a short as far as AC is concerned, the output circuit is thus the same as figure 13C.

Feedback voltage from the output at point A is conducted through the transistor, represented by the feedback path, C_{FB}. This path is not purely capacitive. Instead, there is a resistive component, so that the feedback sees an internal "RC" path from the output to the input. To maintain the correct phase relationship of the neutralizing voltage, a resistor (Rn) and capacitor (Cn) are placed in the neutralizing circuit between point B and the input. The neutralizing voltage and the feedback voltage are thus maintained at equal amplitude and opposite phase.

Resistor R4 in the supply line has several functions. Together with C2, it acts as a decoupling device, preventing IF currents within the amplifier from appearing on the supply line and interacting with the other IF stages. It also allows the lower end of the tank (B) to be above RF ground potential. Without this resistor, the large capacitor at the power supply would place the bottom of the tank at ground potential as far as the IF is concerned, and point B could not be used as a source of neutralizing voltage.[2]

Another 455-KC Amplifier

Figure 15 shows the circuit of a 455-kc amplifier stage utilized in a completely transistorized mobile receiver. The main differences between this circuit and figure 14 are the transistor used, the coupling system and the neutralizing circuit.

Before discussing each of these factors, let's look at the biasing arrangement. With the negative side of the supply grounded, the collector of the PNP transistor returns to ground through the tuned circuit and the emitter connects to the positive side of the supply through stabilizing resistor R3. This resistor is bypassed to avoid degeneration. Resistors R1 and R2 form a voltage divider which establishes the proper bias at the emitter junction.

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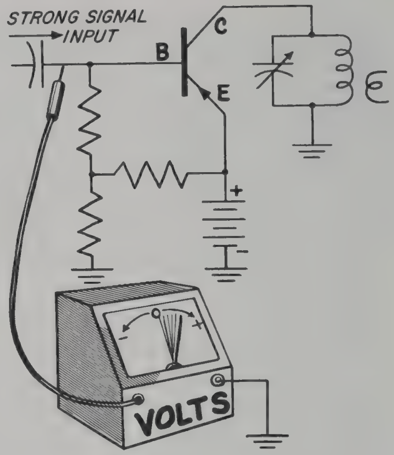
[2] See TM11-690, pages 151-155.

Figure 15 utilizes a 2N247 transistor, a diffused-base type capable of giving considerable amplification at 455 kc. The collector load is a tuned circuit, with a low-impedance secondary winding providing for the low-impedance input to the following stage. The voltage across this secondary winding is out of phase with the primary voltage and thus provides a convenient source of a neutralizing voltage. Neutralizing capacitor Cn feeds back some of this out-of-phase voltage to the input, thereby counteracting the internal feedback of the transistor. The neutralized stage is capable of providing maximum gain with good stability.

The resistor in parallel with the tuned circuit prevents the circuit from becoming too selective and, as a result, reject the sideband energy of the incoming FM signal. The value of this resistor may be changed according to the required bandwidth of the receiver. A smaller value of resistance provides a greater loading of the circuit and hence a broader response. Large resistance values do not load the tuned circuit so much and allow greater selectivity.

The input to this circuit is the output of the Permakay filter. In the receiver there are two more stages of IF amplification, both with circuits similar to that of figure 15.



When the Input Signal Overdrives the Input Circuit, the Base-To-Ground Voltage of the Transistor Limiter Stage Varies in the Positive Direction.

Untuned 455-KC IF Amplifier

A Motorola VHF pocket-type receiver utilizes several stages of 455-kc amplification which do not incorporate any tuned circuits. The stages are RC coupled and, although more stages are required to provide the necessary gain, the selectivity of this 455-kc section of the receiver is achieved in the Permakay filter and additional selectivity is unnecessary.

One of the major advantages of this procedure is the freedom from any tuning within the 455-kc IF amplifier section; this greatly simplifies the alignment. Furthermore, with small resistors in place of tuning coils and capacitors, the receiver may be made more compact.

The circuit of the untuned IF amplifier is shown in figure 16. The three resistors form a voltage divider and provide the bias voltages at the transistor elements. The resistor between the collector and base also gives DC stability to the amplifier and, because it allows a degenerative voltage from the output to the input, it also lowers the amplification. The gain is comparatively low and the circuit does not require neutralization.

In the complete circuit of this pocket-size receiver, three stages within the IF section are placed in series as far as their DC currents are concerned, and this lowers the total current requirement of the receiver. The arrangement of the DC path is shown in figure 17. Bypass capacitors prevent interaction of the stages due to the common DC current through them.

12-MC IF Amplifiers

Both the high-band pocket and mobile receivers, discussed in the preceding section about 455-kc amplifiers, incorporate transistors in their first IF section; the IF stages operate at 12 mc in both instances. One of these amplifiers is shown in figure 18.

The input to the amplifier is the output of the first mixer, and a tuned, impedance-matching transformer is used between the stages. A high degree of selectivity is desired at this point; it is important to select the desired frequency at the mixer output and to reject the others. The output of the amplifier stage incorporates two tuned circuits which are critically coupled, by a capacitor, for maximum gain with good selectivity. The output tuned circuit has a tapped capacitance arrangement to accommodate the low-impedance input to the following stage.

The amplifier stages in the first IF section of this and other Motorola communications receivers are required to furnish a considerable amount of selectivity. This is particularly true when we compare the almost complete lack of selectivity associated with the low-frequency IF amplifier stages. The Permakay filter preceding the 455-kc amplifiers makes it unnecessary to have very much selectivity at this point of the receiver, but the situation at the first IF level is considerably different.

At the first IF section, it is paramount to realize all the selectivity that is practicable, in order to reject as completely as possible the image frequency and those undesirable signals which produce intermodulation and other forms of interference. This accounts for the double-tuned, critically-coupled circuit in the output of figure 18. A double-tuned circuit would also be desirable at the input to this stage. For the desired amount of selectivity and the signal level at this point of the receiver, however, the insertion loss due to the added components would lower the signal-to-noise ratio (sensitivity) of the receiver.

The bias for this PNP diffused-base transistor is secured by a voltage divider, R1 and R2. Bypassed resistor R3 in the emitter return provides for DC stabilization without causing degeneration.

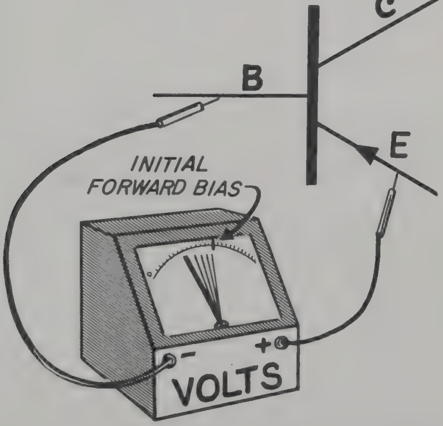
The schematic of another 12-mc IF amplifier is shown in figure 19. This circuit provides a considerable amount of gain, and the selectivity is also good. The circuit is neutralized for maximum stability.

The amplifier utilizes a common-emitter circuit. For the PNP transistor and with the supply voltage having a negative ground, the collector is connected to ground through the primary (P) of transformer T2. The emitter returns to the positive side of the supply through stabilizing resistor RE, and the bypass capacitor prevents degeneration.

Forward emitter bias is established by the voltage divider, R1 and R2. A feedback winding on output transformer T2 becomes the source for neutralization voltage, and CN and RN provide the necessary feedback path but limit the neutralizing energy from the output to the input to the desired value.

The input signal to this stage comes from the mixer, and input transformer T1 has three windings. The primary and secondary S (leading to the transistor base) are both low-impedance windings. Selectivity is provided by the third winding, which is tuned to 12 mc.

There are also three windings on output transformer T2. The primary is untuned and has a relatively low impedance. One secondary (FB) provides the feedback voltage for neutralizing the stage, while the other is tuned, providing selectivity. This tuned circuit is critically coupled by a capacitor to another tuned circuit in order to provide additional selectivity. This second tuned circuit is the primary of another transformer T3, and the untuned secondary is the output of the entire stage and is applied to the input of the next 12-mc IF amplifier.



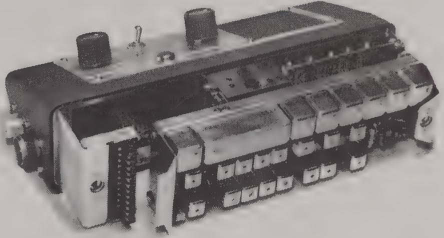
One Test for Limiter, Oscillator and Frequency Multiplier Stages is a Change in Operating Bias at the Emitter Junction.

Transistorized RF Amplifier

Two types of transistors are currently being used for RF amplification in high-band Motorola receivers; these are the mesa and the microalloy diffused (m. a. d. t.) transistors. Figure 20 shows a common-base RF amplifier circuit which accommodates either of these transistors, and the PNP transistor symbol is the same for both.

The common-base circuit has a characteristic high output impedance. Thus, it is not necessary to tap the output tuned circuits in order to match the impedances; the design of the tuned circuits is thereby simplified. In addition, the common-base circuit accommodates a larger input signal, an important factor in two-way mobile receiver operation. The gain of the circuit is not so high that the stage is unstable and requires neutralization. Neutralization of a transistor amplifier which must tune over a considerable frequency range is rather complicated.

There is nothing in the circuit which is unusual or different from the arrangements we have just studied. The great difference is in the frequency involved and the ability of the transistor to provide gain at these frequencies. Selectivity is realized by critically-coupled circuits in both the input and output of the stage, and coupling is determined by the value of the coupling capacitance.



Here We See The Modular Construction of the Transistorized "Dispatcher" Motorola Receiver.

Bias is realized by the now familiar voltage divider, R1 and R2, and emitter resistor Re gives DC stability. For this particular circuit the emitter resistor cannot be bypassed, for the signal would then be shorted to ground. The gain is not so great that it is necessary to neutralize the stage.

We have just seen the application of transistors to both the low and high-frequency IF sections and the RF section of the receiver. In the remainder of this lesson we will see other high-frequency uses of the transistor, as limiters and as oscillators.

Transistorized Limiters

The operation of transistors as limiters in the Motorola Handie-Talkie is not much different from their basic operation as 455-kc IF amplifiers. In fact, the only difference between the first limiter stage shown in figure 21 and the

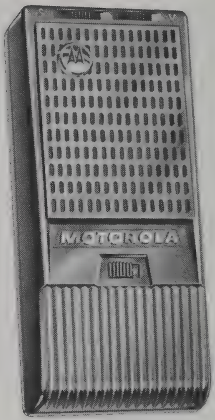
455-kc amplifier of figure 14 is the amplitude of the applied signal.

Operation of the transistorized limiter depends upon the application of a large amplitude signal, the same as the vacuum-tube plate limiter. The collector current of the transistor limiter, like the plate current of the vacuum-tube limiter, is operated between cutoff and maximum (saturation).

We can analyze the operation of the limiters from the circuit of figure 21. With a strong signal applied, the positive alternation of the signal drives the base positive with respect to the emitter; the emitter junction is now reverse biased, and the collector current is zero.

On the negative half of the strong input signal, the base becomes more negative, increasing the emitter-collector current to its maximum value. Once the collector current has reached cutoff and maximum, there can be no further change in the output current regardless of the amount of input.

Thus, by providing a signal of sufficient amplitude to drive the collector current to cutoff and maximum, the transistorized limiter produces an output signal of constant amplitude. However, if the signal amplitude is not sufficient to drive the stage to the limits of collector current, the circuit operates the same as an IF amplifier. Strong signals hold the plate current as cutoff and saturation during the greater portion of each cycle and thereby provides good noise reduction. This effect is discussed in detail in the lesson dealing with vacuum-tube limiters.



This Pocket-Size High-Band Paging Receiver is Completely Transistorized.

In the transistor circuit of figure 21, limiting is evidenced by a change in the negative voltage between the base and ground--this voltage becomes less negative. The amount of change is determined by the amplitude of the input; for a strong signal the base will actually become positive with respect to the emitter. This change of voltage takes place for a strong noise input as well as for a channel signal.

The change of base voltage becomes a convenient means of determining the relative signal strength, so it is used in alignment. In the receiver, three of the metering points measure limiting; these are in the last limiter, the first limiter and the last IF stages. The last limiter has a positive base voltage with only the front end noise applied. This positive voltage increases with a channel signal, to the point where the first limiter reaches saturation and provides a constant output. When this occurs it is necessary to use one of the preceding meter positions for alignment.

Transistorized Oscillators

Transistorized oscillators are not very different from vacuum tube oscillators; in fact, the basic operation is the same. In order to have self-oscillation there must be (1) an amplifying device and (2) regenerative feedback capable of sustaining oscillation.

Figure 22 illustrates the similarity between the two types of oscillators. At A we see a Colpitts vacuum-tube oscillator, in which the plate-tank capacitor is tapped and a portion of the output energy is fed back to the input. The lower part of the tank (C1) is in parallel with the cathode-ground circuit, with the result that some of the energy in the tank circuit is applied to the grid-cathode circuit.

The polarities show the effect when the plate current increases. The upper end of the tank swings negative to the lower end and the upper end of C1 also becomes negative. This voltage applied to the cathode-grid makes the grid positive (or less negative) and causes a further increase of plate current.

The operation of the transistorized oscillator at B is essentially the same as that of the vacuum-tube oscillator. The tank in the output (collector) circuit is tapped and the emitter resistor is in parallel with C1. Any voltage across C1 is automatically applied between the emitter and base.

The signs indicate the voltage polarity when the current is increasing and the feedback makes the emitter positive to the base. For a PNP transistor this further increases the collector current. During the next half cycle when the current decreases, the feedback voltage has reversed polarity and the forward bias of the transistor is reduced. Thus, the feedback voltage is regenerative and makes the circuit self-oscillating.

Figure 23 shows the arrangement of another vacuum-tube oscillator along with the corresponding transistorized circuit. At A we find a tuned circuit between grid and ground with the cathode connected to the tap. As the plate current increases the cathode current also increases and the cathode swings positive. This voltage is applied to the tap on the tank circuit and, due to the circulating current within the tank and the step-up effect of the tuned circuit, a larger positive voltage appears at the grid. With the grid going positive with respect to the cathode, the plate current tends to increase further--this is feedback in phase and produces oscillation.

The common-emitter transistor circuit at B is very similar to that of A; the tank circuit is between the base and ground and the emitter is connected to the tap. Increasing current through the emitter resistor causes a voltage drop as marked and this voltage applied to C1 in the tuned circuit causes a higher negative voltage at the base; the transistor forward bias is increased. This means an increase in emitter current. The action is regenerative and produces oscillation.

It is interesting to note the similarities in the oscillator circuits of figures 22 and 23. Considering the transistorized versions only, the tank circuit in both instances is between the collector and base and the emitter is connected to the tap. The difference in the figures is only in the point of the circuit which is designated as ground.

This Photo Shows the Modular Construction of a Motorola Pocket-Size VHF Receiver.

There are many other oscillator circuits which are found in vacuum tube and transistorized equipment. Regardless of the circuitry, however, they all follow the pattern that some of the output circuit energy is fed back "in phase" to the input and causes oscillation.[3]

Oscillator Emitter-Junction Bias

We have previously discussed the importance of maintaining a constant emitter junction bias for an amplifier, to the point that stabilizing circuits are usually included to keep a steady bias for changes of temperature, etc. This is necessary in amplifiers in order to keep them operating in Class A, in which the stage operates over the linear portion of the curve and the collector current occurs for the complete cycle. This type of operation, however, is not the manner in which the average oscillator operates.

Instead of operating in Class A, it is more likely that the oscillator will be reverse biased at the emitter junction, and collector current occurs for less than a half-cycle of the input (feedback) voltage. This type of operation is known as Class C. Of course, the stage is forward biased initially, for this is necessary to make the transistor conduct. As soon as the circuit starts to oscillate, however, the bias changes.

---

[3] See TM11-690, pages 165-175.

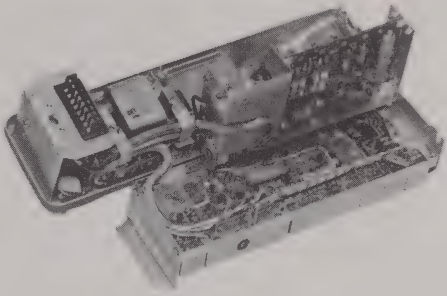
The action of the oscillator bias is the same as that of the limiter stage, which has already been discussed in this lesson. For the oscillator, however, the signal voltage is the feedback from the output to the input. This feedback drives the base further negative than required to cause maximum collector current and, as a result, the base current increases drastically.

This increase in base current causes the base to swing in the positive direction, producing a reverse bias at the junction. In most instances the feedback voltage is sufficient that the stage assumes an appreciable reverse bias; collector current occurs only for a small portion of the cycle, when the base is driven negative by the feedback signal.

The oscillator activity can be readily measured by the change in the base voltage. We will say more about this in the next lesson.

Crystal-Controlled Transistorized Oscillators

A frequency-controlling quartz crystal may be used with the transistorized oscillator just as readily as for the vacuum-tube model. There are two general procedures for inserting a quartz crystal into the oscillator for frequency-control purposes. First, it may be placed in the feedback path so that the only time feedback is established is when the frequency of feedback energy coincides with the natural series-resonant frequency of the crystal. The second method is to use the crystal as part of the tuned tank circuit. We shall inspect each of these briefly.



This Photo Shows the Complete Internal Construction of the Motorola Handie-Talkie Transmitter and Receiver.

The oscillator circuit of figure 24A is the same as that of figure 21B, when the base is at ground potential. Thus, if the crystal has a low impedance so that the base is effectively at RF ground potential, the circuit oscillates in the manner already described.

The only time that the crystal looks like a low impedance is when the currents coincide with the natural resonant frequency of the crystal. The crystal is then series resonant and has a very low impedance; the crystal has a very high impedance to all other frequencies. A high impedance prevents any appreciable RF change of the emitter-base current and the circuit cannot oscillate.

In figure 24B the crystal functions as part of the parallel resonant circuit (the tuned circuit of the oscillator). The tank voltage has a divider made up of C1 and C2, and the voltage across C1 is fed back to the emitter and produces oscillation. This circuit is again electrically the same as figure 21B. The only difference is the use of the crystal as part of the tank circuit.

Here We See a Battery Supply for a Portable Two-Way Radio.

12-MC Oscillator

Figure 25 shows the low-frequency oscillator of one of Motorola's completely transistorized receivers. The frequency, in the 12-mc range, is determined mainly by the resonant frequency of the crystal.

Coupling capacitor (C) and the load (R) are in parallel with the collector coil (L).

The load has a low impedance, so in effect the capacitor is in parallel with the coil. If we omit the DC biasing components, the circuit simplifies to that shown in figure 25B. Assuming that the circuit is capacitive between the collector and ground--and it is so designed--the circuit is the same as that of figure 24B. Coil L is a means of completing the DC path for collector current without introducing a resistor, which always causes a power loss and poor efficiency.[4]

Transistorized High-Frequency Oscillator

Figure 26 shows the basic circuit of a transistorized, crystal-controlled, high-frequency oscillator used in a high-band mobile receiver. The operating range of the oscillator is around 28-32 mc and this signal is multiplied to the fifth harmonic, producing an output to the mixer between 140 and 160 mc.

The oscillator circuit is essentially the same as that of figure 24A. The emitter is connected to a capacitive tap on the tuned circuit and the output of the oscillator is taken from this same low-impedance point. The crystal in the base return circuit acts like a series-resonant circuit and because of its low reactance at its resonant frequency it allows the circuit to oscillate at this rate.

The resistor parallel to the collector tuned circuit broadens the response of the circuit. This allows for the collector circuit to be tuned with but a minimum effect upon the oscillator frequency. The oscillator frequency is controlled by the variable capacitor in series with the crystal. Varying the

[4] See TM11-690, pages 175-177.

amount of reactance in the crystal current path causes a change in frequency, the same as was accomplished for vacuum-tube receivers.

Frequency Multiplier

We found, in our study of crystal-controlled oscillators for high-band receivers, that oscillators at the mixer injection frequency are not practicable; instead, a low-frequency oscillator is used, followed by a frequency multiplier. The output circuit of the multiplier is tuned to a harmonic of the input signal, thereby making that harmonic frequency available for injection at the mixer.

Figure 27 shows a typical multiplier circuit, which follows the high-frequency oscillator in a high-band transistorized receiver. This circuit operates at the fifth harmonic of the oscillator frequency. By operating the stage in Class C and tuning the collector circuit to the desired harmonic frequency, the output frequency is five times higher than the oscillator frequency.

Class C operation is established by having a strong signal at the input (base), thereby driving the stage beyond the normal range of collector current. Again the same action takes place as was discussed for the limiter and oscillator stages, in that the base current increases considerably and reverse biases the emitter-base junction.

Collector current occurs as short pulses, each lasting for a very small part of the complete cycle of input signal. The collector load consists of three high-Q, critically-coupled circuits tuned to the fifth harmonic of the input signal. Because of the selectivity of the tuned circuits, all frequencies except the fifth harmonic are attenuated and only the desired signal reaches the mixer with appreciable amplitude. The output tuned circuit is tapped to provide the low-impedance input to the mixer.

Discriminators

Discriminators and other forms of FM detectors require two diodes. It does not matter whether these are vacuum-tube diodes or semiconductor diodes, for the circuit operation remains the same.

If semiconductor diodes are used, they should have a good front-to-back resistance and conduction ratio. That is, the conduction should be good in one direction, but the resistance in the other direction should be very high. In addition, a diode capable of operating at higher temperatures without changing conduction characteristics is important, for in two-way equipment the operating temperature is often at the extremes of heat and cold. Thus, silicon diodes are the most satisfactory.

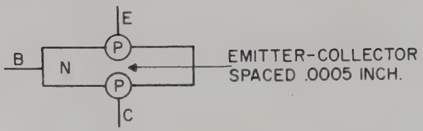
The operation of the circuit remains the same regardless of the type of diode used. Discriminator operation is described in complete detail in an early lesson, in the receiver section of this training.

This concludes our discussion about the use of transistors in high-frequency applications. The next assignment is devoted to the subject of servicing transistorized equipment.

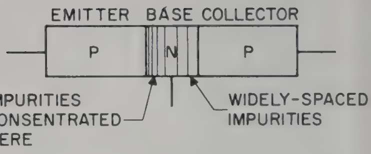
STUDENT NOTES

STUDENT NOTES

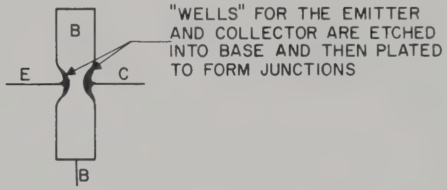
STUDENT NOTES



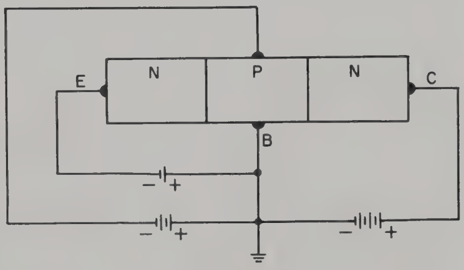
ALLOY JUNCTION TRANSISTOR
FIGURE 1



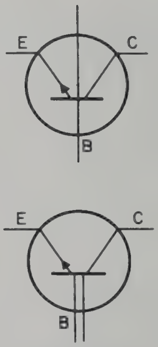
DIFFUSED-BASE TRANSISTOR
FIGURE 2



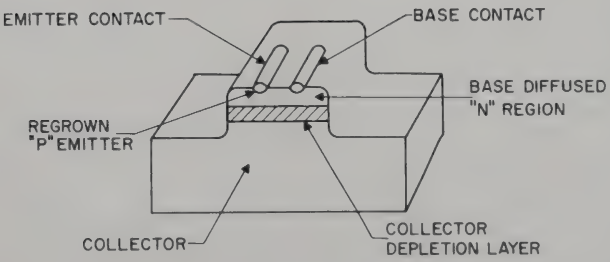
SURFACE-BARRIER TRANSISTOR
FIGURE 3



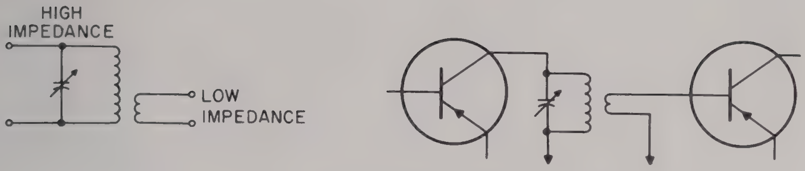
TETRODE TRANSISTOR
FIGURE 4



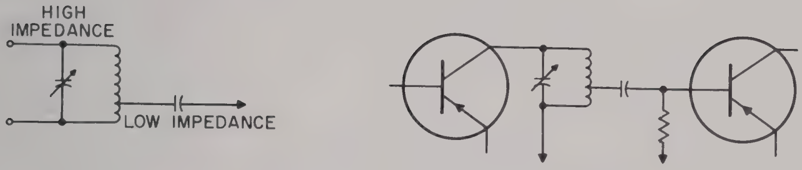
NPN/TETRODE
SYMBOLS



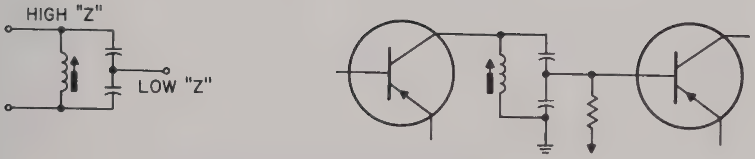
MESA TRANSISTOR
FIGURE 5



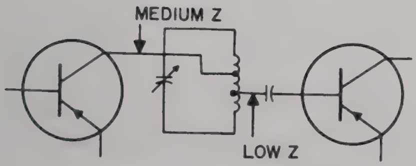
TRANSFORMER COUPLING
FIGURE 6



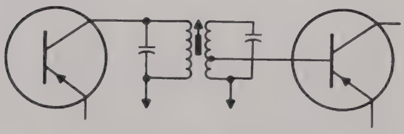
"TAPPED" COIL COUPLING
FIGURE 7



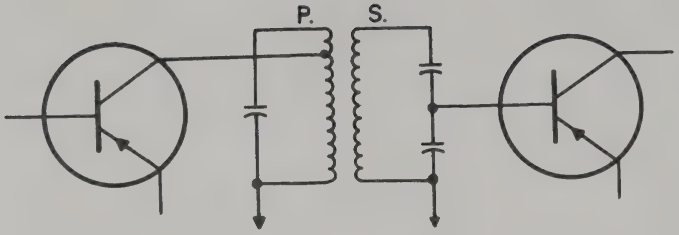
"TAPPED" CAPACITOR COUPLING
FIGURE 8



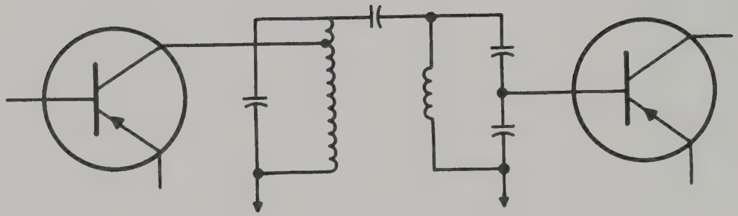
"DOUBLE-TAPPED" COIL
FIGURE 9



"TAPPED" SECONDARY
FIGURE 10



A
INDUCTIVE COUPLING



B
CAPACITANCE COUPLING

FIGURE 11

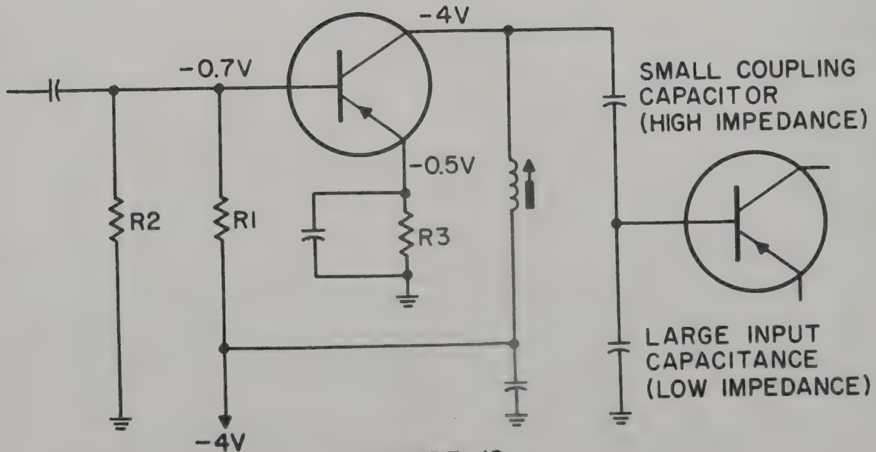
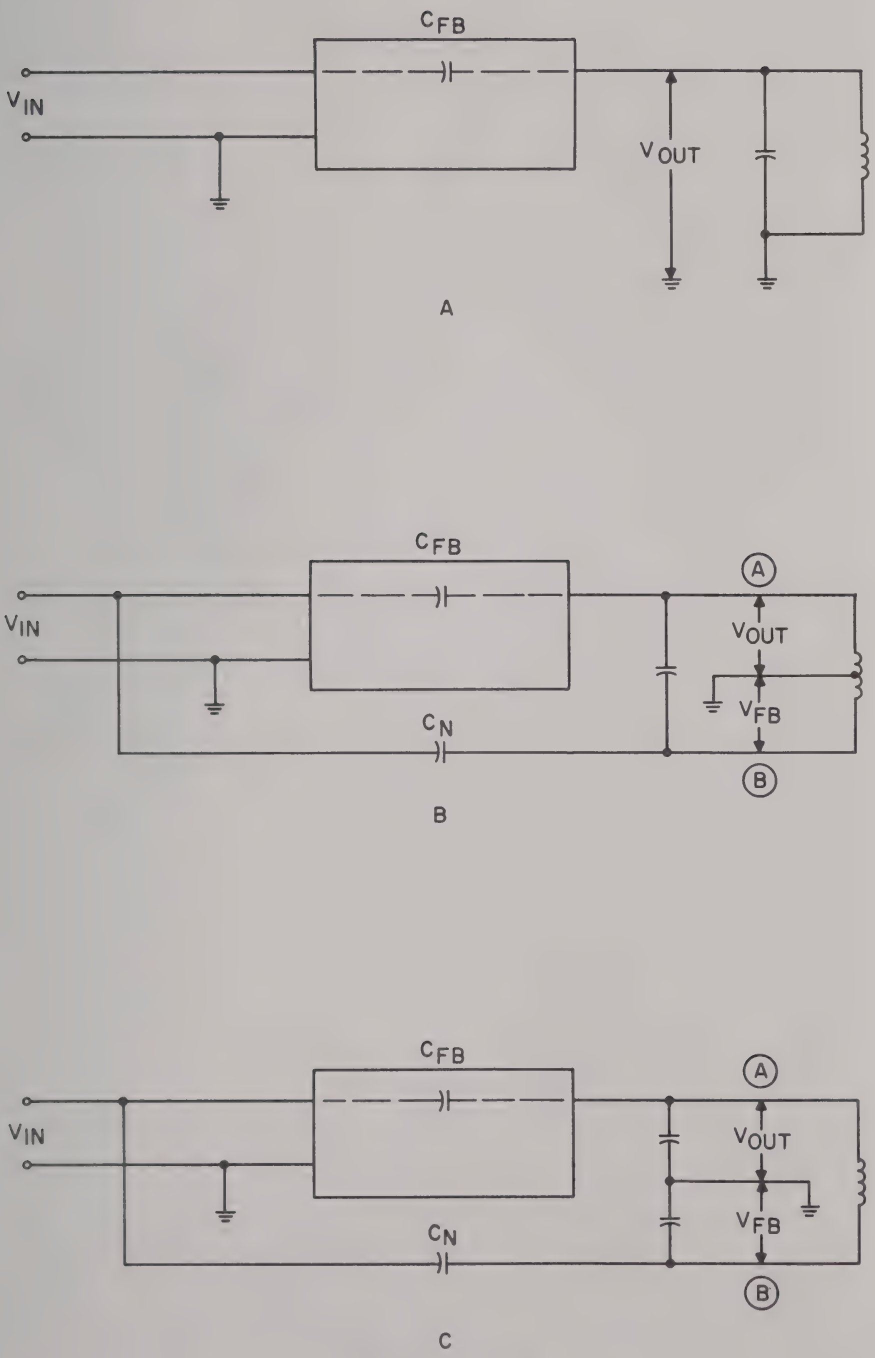
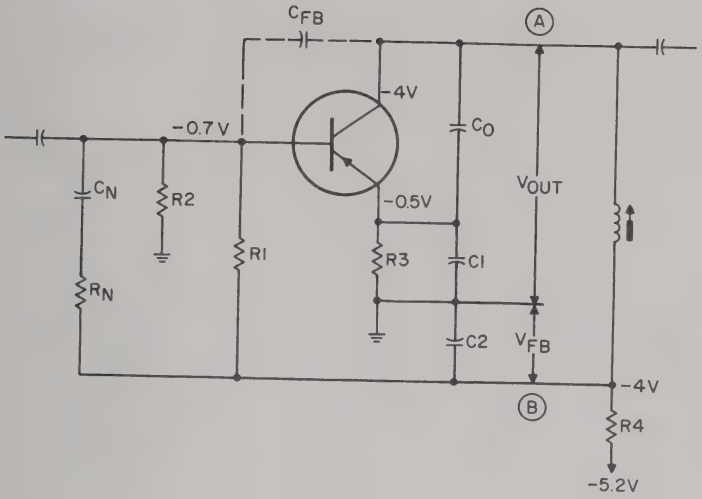

-4V
-0.7V
-0.5V
R2
R1
R3
SMALL COUPLING CAPACITOR (HIGH IMPEDANCE)
LARGE INPUT CAPACITANCE (LOW IMPEDANCE)
-4V

FIGURE 12

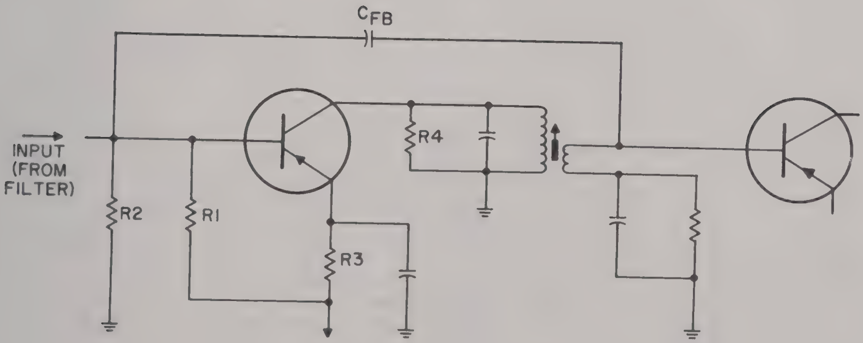


NEUTRALIZATION

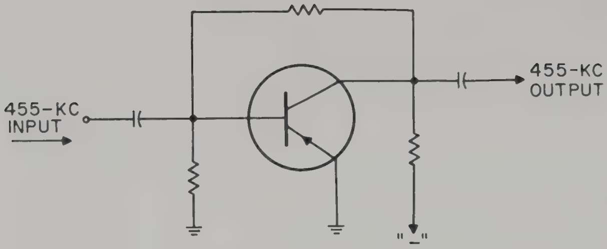
FIGURE 13



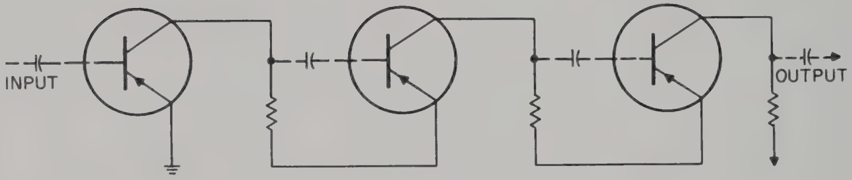
455-KC IF AMPLIFIER
FIGURE 14



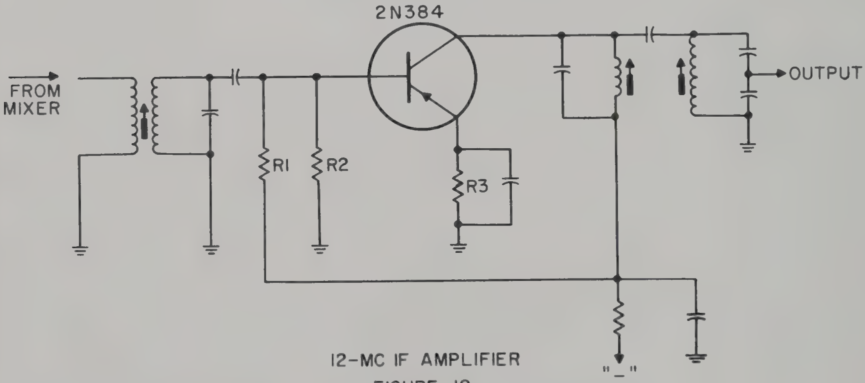
455-KC IF AMPLIFIER
FIGURE 15



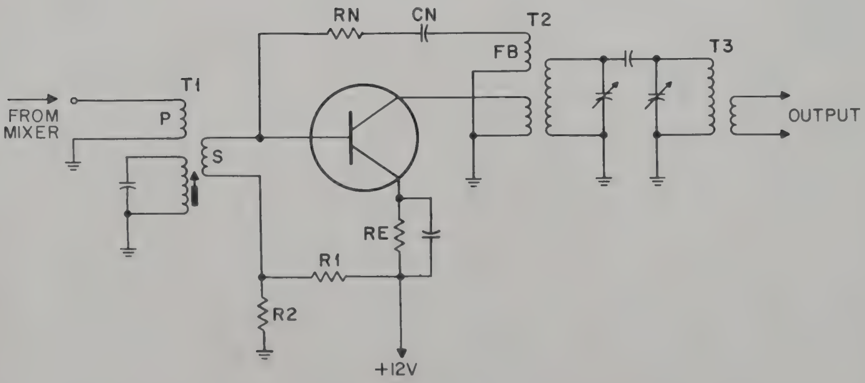
UNTUNED IF AMPLIFIER
FIGURE 16



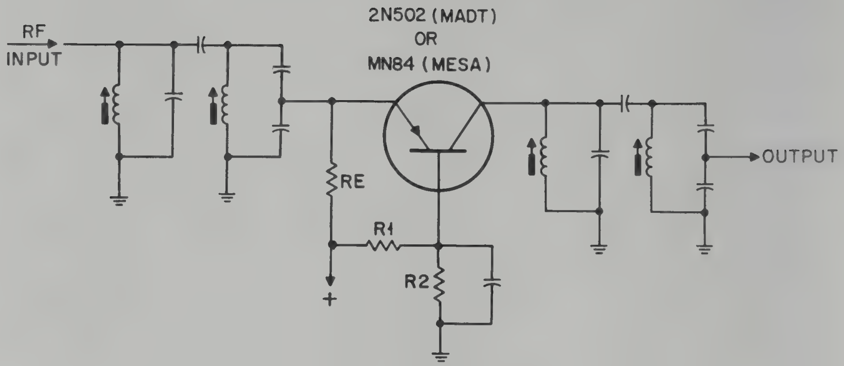
DC SERIES-CONNECTED STAGES
FIGURE 17



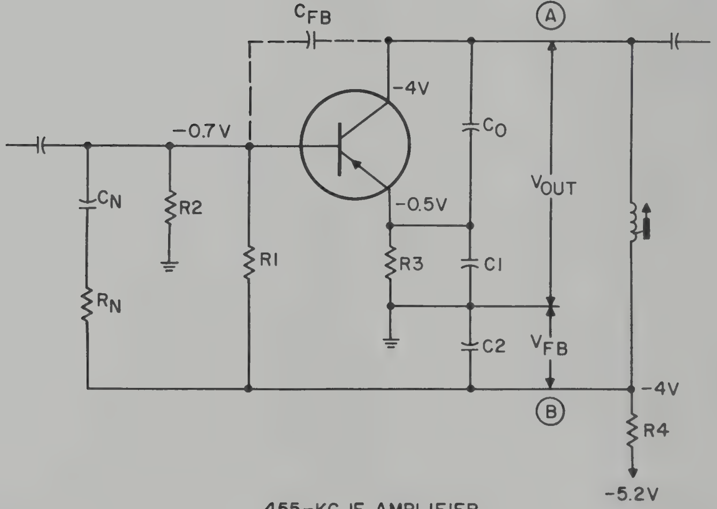
12-MC IF AMPLIFIER
FIGURE 18



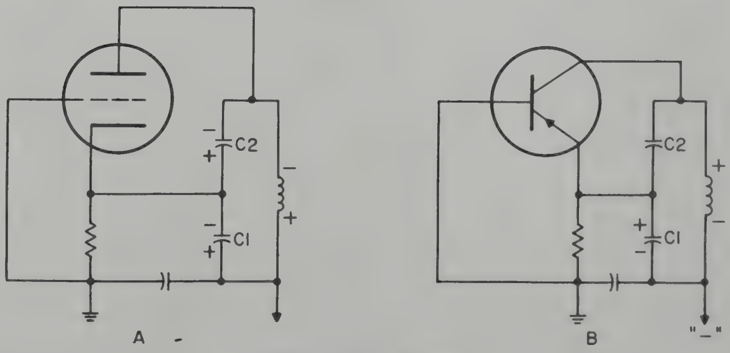
12-MC IF AMPLIFIER
FIGURE 19



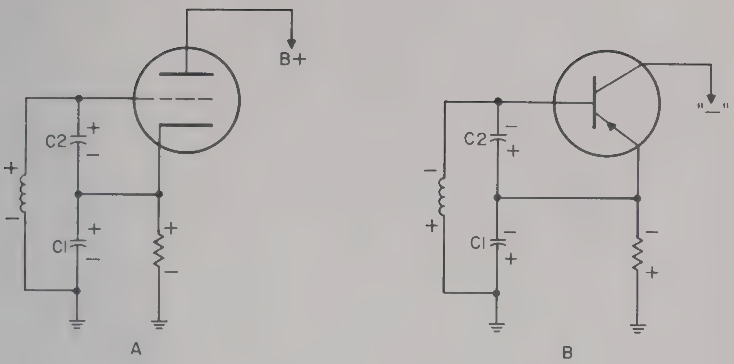
RF AMPLIFIER
FIGURE 20



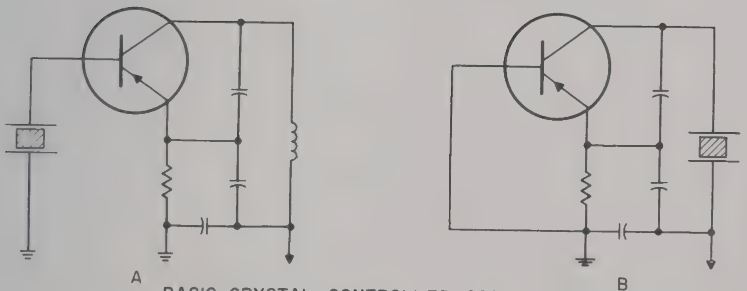
455-KC IF AMPLIFIER
FIGURE 21



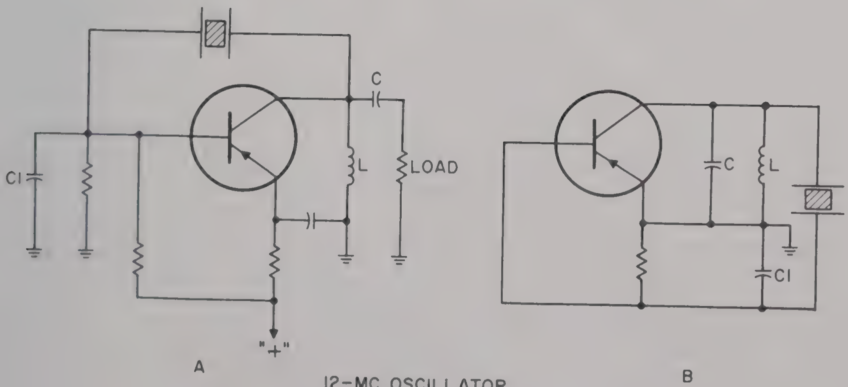
BASIC OSCILLATORS
FIGURE 22



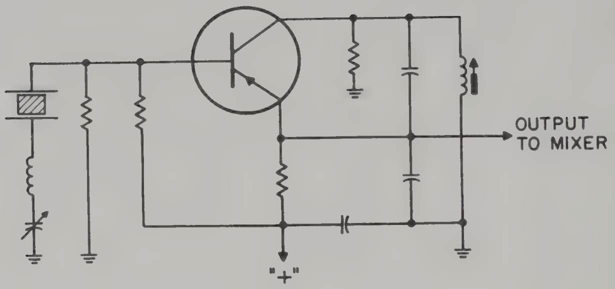
BASIC OSCILLATORS
FIGURE 23



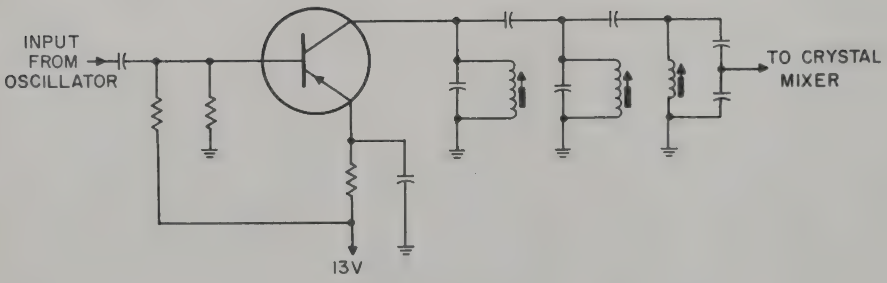
BASIC CRYSTAL-CONTROLLED OSCILLATORS
FIGURE 24



12-MC OSCILLATOR
FIGURE 25



HIGH-FREQUENCY OSCILLATOR
FIGURE 26



MULTIPLIER (RECEIVER-OSCILLATOR)
FIGURE 27

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City ______________ State ________ Grade ______

EXAMINATION, LESSON SA-7

1. Which of the following factors limit the high-frequency operation of transistors?
   - A. The transit time of the carriers across the emitter junction. ______
   - B. The capacitance of the junctions. ______
   - C. The limited power handling capability of transistors. ______
   - D. The base resistance. ______

2. The diffused-base transistor is different from other types of transistors in that the (emitter) (base) (collector) has a varying concentration of (impurity atoms) (N- and P-type atoms), so that a "built in" electric field is established in the (emitter) (base) (collector). Carriers encountering this field are (accelerated) (slowed up) (kept at a constant speed) and thereby cross the (emitter) (base) (collector) region (at a more steady rate) (in less time) (in the exact time it takes for one-half cycle of input signal). In addition, due to the reduced concentration of (impurity atoms) (both P- and N-type atoms) near the collector junction, the (input resistance) (output capacitance) is less, providing a (higher) (lower) output impedance.

3. Indicate which of the following characteristics apply to the "mesa" transistor.
   - A. The base region is diffused. ______
   - B. The large collector junction is alloyed to the base. ______
   - C. The method of manufacturing this transistor allows close control of the important parameters. ______
   - D. The manner of producing and the design of the transistor limits its power capabilities. ______

4. Figure A shows a method of coupling between two transistorized stages. The input impedance of this coupling system is (higher) (about the same) (lower) than the output impedance.

5. Figure A shows a means of coupling by using a single tuned circuit with the low-impedance secondary connecting to the base of the second stage. In figure B, there are two tuned circuits, with the low-impedance input to the next stage provided by a tap on the second tuned circuit. Assuming that the Q's of the tuned circuits are the same, this circuit provides greater selectivity and the degree of coupling is determined by the capacitor between the tuned circuits. TRUE______ FALSE______

6. In order to neutralize an amplifier, a second signal voltage which is out-of-phase with the internal feedback voltage must be established. This second voltage opposes the feedback voltage, so that as far as the stage is concerned there is no feedback and the only input is the signal applied from the preceding stage. TRUE______ FALSE______

7. The high-frequency IF amplifiers in the two-way mobile communications system usually have a greater degree of selectivity per stage than the low-frequency IF stages. The reason for this is: (Choose one answer).
   - A. Greater selectivity is needed. ______
   - B. There are more stages in the low-frequency section; therefore, each stage requires less selectivity. ______
   - C. There is a high selectivity filter preceding the low-frequency stages which provides nearly all the selectivity needed at this section of the receiver. ______
   - D. Selectivity is easier to accomplish at higher frequencies. ______

8. For the average transistorized limiter stage, the presence of limiting or clipping is evidenced by: (Choose one answer)
   - A. The emitter voltage swings more positive. ______
   - B. The emitter voltage becomes less negative. ______
   - C. The base voltage swings in the positive direction. ______
   - D. The base voltage swings more negative to the emitter. ______

9. In order to have one type of transistor oscillator:
   - A. The collector and base are connected to opposite ends of the tuned circuit and the emitter is connected to the tap. ______
   - B. The emitter and base are connected to the ends of the tuned circuit with the collector connected to the tap. ______
   - C. The collector and emitter are at the ends of the tuned circuit and the base is connected to the tap. ______
   - D. It doesn't make any difference which transistor elements are connected to the tuned circuit terminals; so long as the feedback is degenerative the circuit will oscillate. ______

10. In some transistor oscillator circuits, the crystal acts as a part of the parallel tuned circuit; in others it acts as a high impedance (at resonance) in series with the feedback path. TRUE______ FALSE______

FIGURE A

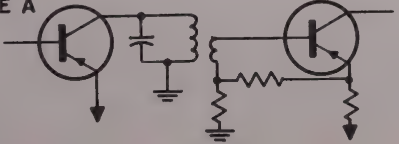
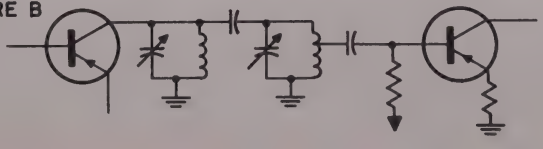


FIGURE B



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LESSON SA-8
TRANSISTORS

Servicing Transistorized Equipment

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LESSON SA-8
TRANSISTORS

Servicing Transistorized Equipment

—one of a series of lessons on two-way FM communications—

MOTOROLA TRAINING INSTITUTE
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PREFACE

This is one lesson of a complete Motorola Home-Study Course which presents to the Service Technician both the principles of operation and the maintenance of two-way FM radio systems. The program covers mobile, portable and base station equipment, including the latest transistorized units.

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SERVICING TRANSISTORIZED EQUIPMENT

LESSON SA-8

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NOTICE

Diagrams and figures referenced in text are "fold-outs" in back of each lesson, for use while studying. The Examinations are also there.

Adequate bench space and equipment is needed for efficient servicing of mobile radios. Reference literature is also conveniently located. This Maintenance Center accommodates several technicians.

SERVICING TRANSISTORIZED EQUIPMENT

Lesson SA-8

Introduction

When the two-way service technician who has been accustomed to vacuum-tube equipment first encounters completely transistorized units having modular construction, he is likely to get the impression that here is something entirely new and that he must now "start from scratch." This feeling is unchanged when he contemplates the procedures for changing component parts or making voltage and resistance checks within the equipment. This serviceman is in for a pleasant surprise when he starts to troubleshoot the equipment, however, for he now realizes that he uses the same procedures he followed for vacuum-tube equipment. Thus, although the technician must learn some new techniques about working with transistors, he will make good use of what he already knows.

In this lesson we shall be concerned with the service of transistorized power supplies as well as with transistorized receivers. Because these units are considerably different in their operation and are located on different chassis, we shall discuss them separately, starting with the receiver. In our discussions we shall assume that previous lessons dealing with vacuum-tube receiver service and transistor power supplies have already been studied.

Shock Hazard

One of the most notable differences in working with these receivers is the absence of high voltages which constitute a shock hazard. Because all the stages require low voltages and thus operate directly from the vehicle battery, there is no high voltage at the receiver. Voltage measurements and other service procedures may be performed without the usual precautions against contacting high-voltage points.

Under normal conditions the 12-volt supply line to the receiver does not cause any sensation if contacted directly. This does not mean that the serviceman may become careless in his work habits, however, for screwdrivers, test leads and other tools may "slip" and short out a component or circuit and damage the transistors. Transistors are very sensitive to surge currents; vacuum tubes are not.

Another word of precaution is necessary. The serviceman must not become so careless in his working habits as to forget about high voltages when it comes to working on the transmitter or power supply. Or, while working on the receiver, the transmitter may be turned on inadvertently so that high voltages are present in the complete assembly. Although there are no high voltages at the receiver, the serviceman may have his hand or arm laying across a high-voltage point in the transmitter or power supply!

The Shock Hazard Inherent to Tube-Type Receivers is Not Present in Transistorized Receivers.

Receiver Supply Voltages

The receiver power supply is not considered as an integral part of the receiver. In any troubleshooting plan, however, we must not overlook the fact that the receiver cannot operate normally if the supply voltage is improper. The problem is less complicated for transistor units, for transistors all operate from one common supply voltage; in contrast, vacuum-tube receivers require a variety of voltages for the tube filaments, screen grids and plates.

It is common to have at least two supply voltages to vacuum-tube receivers, whereas transistorized models require only one supply line. Furthermore, the transistorized mobile receiver operates directly from the primary source; there is no power supply to convert the primary voltage to some other values.

We need make but one voltage check in the receiver to determine that the supply is normal and in mobile applications where the battery is capable of delivering a large amount of current, the low drain of the receiver is not likely to cause the battery to "run down" in a short time. For portable units, the power supply consists of a few batteries or a small "power pack" and is a more likely source of trouble.

In two-way radio equipment, receiver failure may be due to a drop in the primary power source, and it is well to first check that the supply voltage at the receiver is normal. We must not forget that relays and fuses in the control line may also be a source of trouble.

In the rest of our discussions about receiver service we shall assume that the power source has been checked and found to be normal, so that any trouble must be in the receiver circuits. In addition, we shall assume that the antenna and antenna relay are normal.

Metering Methods

In analyzing vacuum-tube communications receivers, we found that test points in certain circuits were very helpful in localizing a trouble to some stage or portion of the receiver. The same applies to transistor receivers, for again the trouble must be traced to some section or stage before the exact defect can be determined.

Motorola transistorized mobile receivers have the same metering system as the vacuum-tube versions. That is, the various test points are connected to terminals of a socket and when the Motorola Test Set is plugged in, the circuits may be quickly checked by means of the switch (on the test set).

Figure 1 shows the block diagram of the high-band Motorola transistorized receiver, including the various test points. The block diagram is not any different from vacuum-tube models, and this could well be a vacuum-tube type. We can expect to measure the discriminator output in position 4, and the oscillator is measured in position 6, the same as was done in other Motorola receivers. There are some variations from one model receiver to another, however, and the instruction manual will give details concerning any receivers which are new to you.

The manner of providing the readings for transistorized receivers is not always the same as was done for vacuum-tube receivers, but this is of no consequence so long as the reading indicates the operating condition of the receiver at that point. To illustrate the differences in providing readings, for figure 1 the readings of positions 1, 2 and 3 are due to the RF level in the output circuit of the stage, and are secured by placing a rectifier diode and filter in parallel with the output circuit and reading the relative strength of the RF by the amount of rectified DC.

In vacuum-tube models the corresponding metering positions are found in the grid circuits of the tubes and the readings are the result of grid rectification of the signal within the tube. These readings are in reality a measure of the amount of limiting taking place. In either case, however, the readings are a reasonable indication of the amount of RF present at that point of the circuit.

The Motorola pocket-sized, two-way receivers do not have a plug-in arrangement like the mobile units, and for several reasons. First, the small size of the unit does not allow for a plug without requiring a larger chassis and case. Second, the receiver chassis is readily available accessible for testing purposes, so that it is just about as easy to make voltage checks at the color-coded test points with a regular voltmeter as it is to use the test set.

Some of the test points in the pocket-size receiver require the use of an AC voltmeter, and adapters are available which can be used in connection with the Motorola test set.

Localizing the Trouble

The same procedures used in localizing the trouble in the vacuum-tube receiver are followed for the transistorized receiver. Up to the point of determining the specific component which is defective, the serviceman need not be concerned whether the receiver uses vacuum tubes or transistors.

There are four specific procedures which the technician may follow in his efforts to identify the trouble. While these have already been discussed in a preceding lesson about receiver servicing, we shall make a quick review of them here.

1. Operate the receiver controls to determine whether there is noise present and, if there is, how much? Also, if noise is present, does the receiver respond normally to the adjustment of the squelch control?

   According to his findings, the serviceman may know just about where the trouble is and resort to a more detailed scrutiny of the squelch and audio sections with the use of a voltmeter, or he may deem it necessary to employ additional procedures to isolate the trouble.

2. Take meter readings, using either the Motorola test set or a voltmeter, whichever is called for according to the receiver being tested. These meter readings yield an overall view of the operation of the front end portion and low-IF section of the receiver, including the limiters and discriminator.

   If a channel signal is available, the readings take on greater value; by observing any changes in the readings, we may determine whether more detailed troubleshooting should be performed in some particular section of the receiver, or whether additional efforts to localize the trouble to some stage are needed.

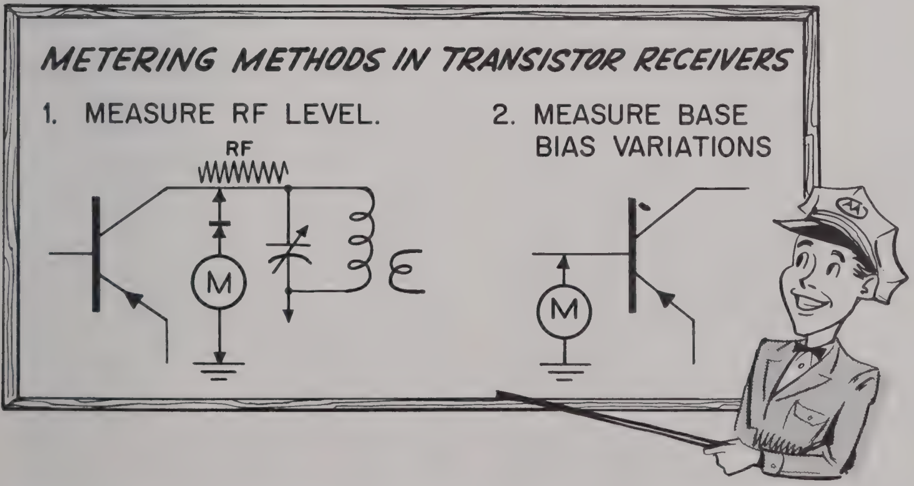
3. Alignment procedures are helpful in determining the operation of the tuned stages. Where a tuned circuit provides normal changes in the meter readings when adjusted, it is

permissible to temporarily assume that the stage is normal. Failure of a tuned circuit to produce the proper changes in meter readings as the circuit is tuned is often valuable in diagnosing trouble.

4. Another method of determining the stage or section of the receiver giving trouble is to make stage-gain measurements. This procedure may be of more value and used more often with transistorized receivers than with vacuum-tube types, and for two reasons. First, with vacuum tubes it is relatively simple to change a tube and compare results. This is not true of transistors. Second, although vacuum tubes have been the most common source of trouble, transistors are not.

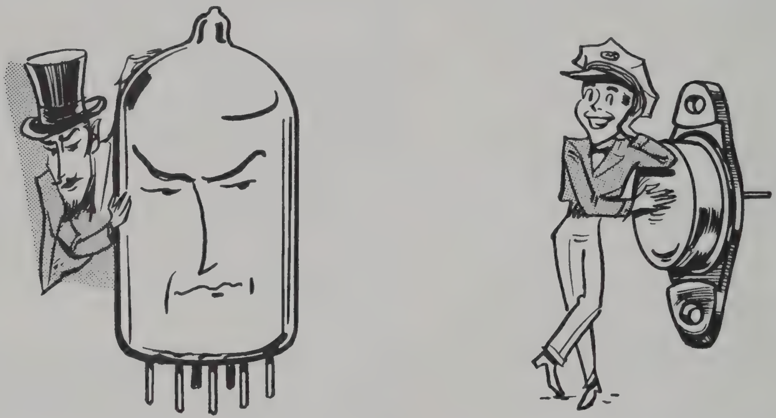
The serviceman will probably make complete checks and be reasonably sure that a transistor is defective before any substitutions are made. This is particularly logical when we consider that transistors are more durable and are not likely to become defective as quickly or as frequently as do vacuum tubes. Thus, it will be best for the serviceman to be reasonably sure of the probable trouble before substitutions are made. More detailed stage-gain measurements will probably be necessary.

The transistor has already lived up to its promise of being a very rugged and nearly trouble-free device. For this reason, it is about the last unit in which we should expect trouble and it is not wise to substitute transistors merely on the assumption that one might be bad.


METERING METHODS IN TRANSISTOR RECEIVERS
1. MEASURE RF LEVEL.
RF
M
2. MEASURE BASE BIAS VARIATIONS
M

Either or Both of These Metering Methods May Be Encountered in the Transistorized Communication Receiver.

Transistors are not a major source of trouble in the transistorized receiver and they are often soldered directly into the circuit rather than use sockets. Although this makes it a little more difficult to replace transistors, it insures longer positive contacts to the transistor and avoids one major source of future trouble.



Tubes Have Always Been a Source of Trouble: Transistors Are Nearly Trouble-Free.

Isolating the Fault Within a Stage

After a specific stage has been identified as the cause of the inoperation or poor operation of the receiver, the next step is to determine which specific component within the stage is defective. This may require any or all of the following: voltage measurements, resistance and continuity checks, and a visual inspection.

Although we may suspect the transistor as being the most likely source of the trouble, it is best to know for certain what is at fault before changing parts. A defective transistor will generally show up in voltage checks, for it has been found thus far in working with transistor circuits that the transistor usually becomes "real bad" rather than develop some minor trouble. As a result, there is a notable change of circuit voltages.

All changes of operating voltage are not due to defective transistors, however, for there are other components which cause similar changes in the voltages when they become defective. Thus, in addition to voltage checks, it is almost essential to make resistance and continuity tests of the components. We shall now discuss each of these in greater detail.

Voltmeters

Before making any voltage measurements, it is important to first know what types of voltmeters are permissible to use in transistor circuits. It is generally accepted that any voltmeter is suitable for measuring the voltages of transistor circuits and that it is not necessary to have a vtvm (vacuum-tube voltmeter). Although this is true for most voltage measurements, there are some instances where meters of lower sensitivity produce erroneous and misleading readings.

Meters with low sensitivity of 1000 ohms/volt are not very satisfactory, for when used on their 10-volt scale they have an internal resistance of only 10,000 ohms, and this can change the operation of the circuit considerably when connected in parallel with certain circuit sections.

Meters with 20,000 ohms/volt sensitivity are better, for on their 10-volt range they present an internal resistance of 200,000 ohms. There are not many transistor circuits where this amount of resistance will alter the operation of the circuit to any appreciable amount. The vtvm is still better, for on any DC scale the meter has a resistance of about 11 megohms.

The voltage readings associated with transistor circuits appear to be very low if we are accustomed to vacuum-tube equipment. The two-way radio using tubes usually has a 200-volt supply for the screens and plates. By comparison, the transistorized two-way receiver operates from a 12-14 volt supply, which is less than one-tenth of the other. For this reason we can expect to use the lower scales of the meter. A 0-30 volt scale is suitable for the higher voltages, but there are some values which are less than one volt and require a 3-volt or even a 1-volt range (full-scale deflection).

In taking voltage readings for any electronic equipment it is generally conceded that a 10% variance is permissible. Many of the circuit components have a 10% tolerance, and when several such units are combined into the same circuit, it is surprising that the voltages as a whole stay so close to the average value.

When we consider a 10% variation for a 200 volt supply, or for a 100 volt rating of a screen grid, we are dealing with a 10- or 20-volt variation from the recommended value and still have an acceptable reading. Continuing our comparison, 10% of the voltages found in transistor circuits will be around 1 volt or less. In fact, as we shall see, there are some voltages which must be measured accurately to within "tenths" of a volt in order to determine the actual operation of the circuit.

Summarizing our discussion of voltmeters, we reach the following conclusions:

1. Although other types of meters may be used for most

measurements in transistorized circuits, it is best to use the vtvm in order to assure accurate readings for all circuits which might be encountered.

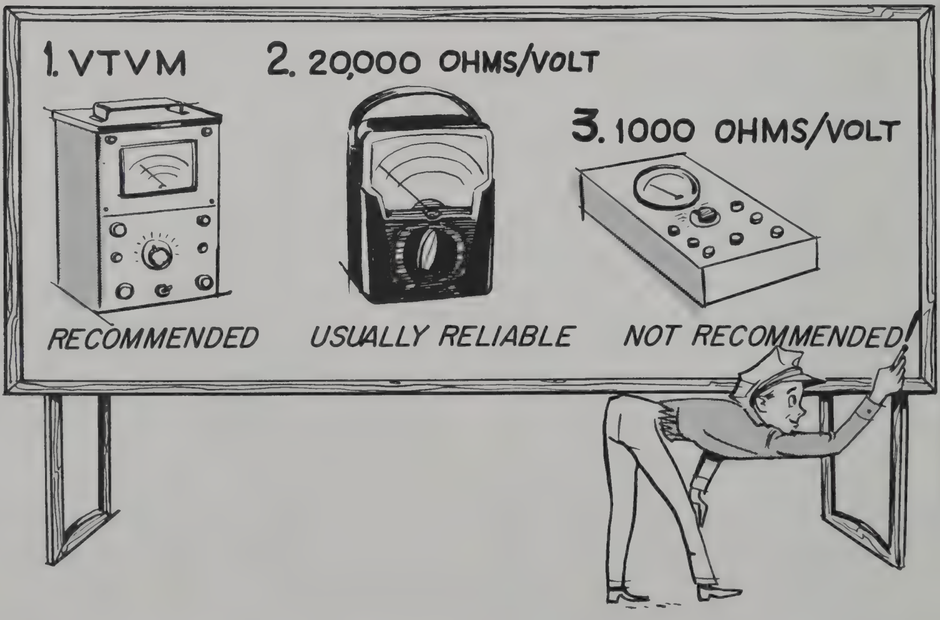
2. Lower voltage scales are required for transistorized equipment, due to the lower supply voltages and the low voltages at the various circuit terminals. The meter should have a range as low as 3 or even 1 volt for full scale deflection.

3. The 10% variation in readings which applies to vacuum-tube equipment also applies to transistorized receivers, but 10% of the relatively low voltages encountered in transistor circuits is usually 1 volt or less.

We are now prepared to proceed with a discussion about those voltage readings in transistor circuits.

Voltage Measurements

In using the meter to measure any voltages associated with transistors (the same also applies to vacuum-tube circuits), we should be aware of any effect the meter might have upon the operation. It is possible for the meter to actually change the operation of the circuit being tested to the extent that the equipment actually becomes inoperative during the test.



Whenever Possible, Use a VTVM; Don't Rely on Less Sensitive Meters.

The proper methods of connecting meters into transistor circuits in order to measure voltages is illustrated by figure 2. Here we see the DC circuit of an RC-coupled amplifier. The capacitors, which have little effect upon the DC voltages, have been omitted for simplicity.

One of the first rules which is well to observe, is not to measure voltages directly between the various elements of the transistor. Although this is permissible in some instances, in others the presence of the test leads will change the operation sufficiently that the readings are not accurate. Instead of measuring between elements, then, it is better to measure the voltage at each element with respect to ground and, from these readings, determine the actual voltage between the elements. Look at figure 2.

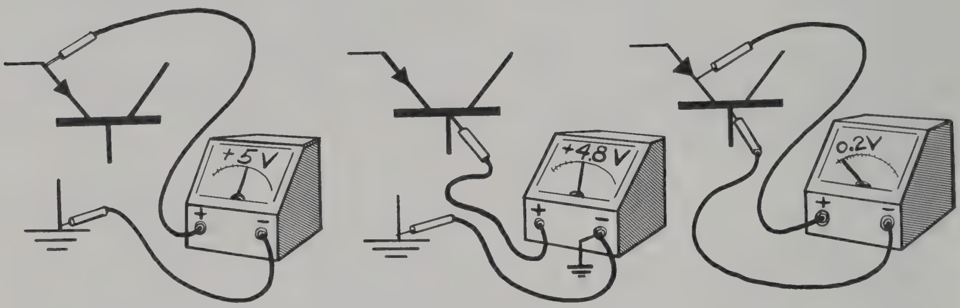
Suppose that we wish to measure the emitter junction bias of the transistor, the voltage between the emitter and base. From the voltages given in the figure, the emitter should be -1 volt to ground and the base -1.2 volt to ground. Because these are both negative voltages with respect to ground, the actual emitter-base voltage will be the difference in these voltages, or 0.2 volt, with the base being negative. Therefore, the emitter junction should be forward biased.

The separate voltages are now measured with a meter. With the positive side of the supply grounded, the voltages of the circuit will all be negative with respect to ground; this means that the positive test lead is connected to ground and the negative lead to whichever point we wish to measure.

In measuring between the emitter and ground, we actually measure the voltage drop across emitter resistor RE. Similarly, in measuring the base-ground voltage, we record the voltage drop of R2. If the voltages are reasonably close to the recommended values we can assume that the stage will be near normal, for the forward bias of the transistor is the major consideration in controlling the operation of the stage.

A check may be made on the drop across collector load resistor RC; with the collector-ground voltage equal to 3.5 volts and with a six-volt supply, the drop across the collector resistor must be the difference in these voltages, or 2.5 volts. (This is in agreement with the basic principle that the sum of the voltage drops about any one circuit must equal the supply voltage.) In a similar manner, if the voltage across R2 is 1.2 volts, the voltage across R1 must be 4.8 volts, for these two resistors are also in series with each other and connected across the supply.

As soon as these voltages have been measured, the operating voltages at the transistor elements can be readily determined. The forward bias of the emitter junction has already been dis-



Do Not Measure Emitter Junction Bias Between the Emitter and Base: Instead, Measure Each with Respect to Ground.

discussed. The reverse collector-base bias is the difference of the voltages of the collector and base, measured with respect to ground; as indicated in figure 2, this is 2.3 volts. The collector-emitter voltage should be 2.5 volts, the difference between the emitter and collector voltages.

There are several additional factors about the forward bias in figure 2 which warrant discussion. The most important is to measure the voltages carefully, for a small error in either the base or the emitter readings with respect to ground may cause a large change in the calculated bias voltage. Let's take an example.

Suppose that the meter reading for the base voltage is actually 1.3 volts, but the serviceman, knowing that the reading should be around 1.2 volts, decides that the reading is okay. "Close enough," he says to himself (the value is within 10% of the correct amount).

Let us assume further that the actual emitter voltage is 0.9 volt. Again the serviceman notes that the value is within 10% of the suggested reading of 1 volt and assumes that everything is normal. Is it, however? NO! The actual bias voltage between the emitter and base is 0.4 volt, twice the desired value of 0.2 volt. Obviously there may be something wrong with the operation of the stage if the forward bias is double what it should be! A further detailed check is indicated.

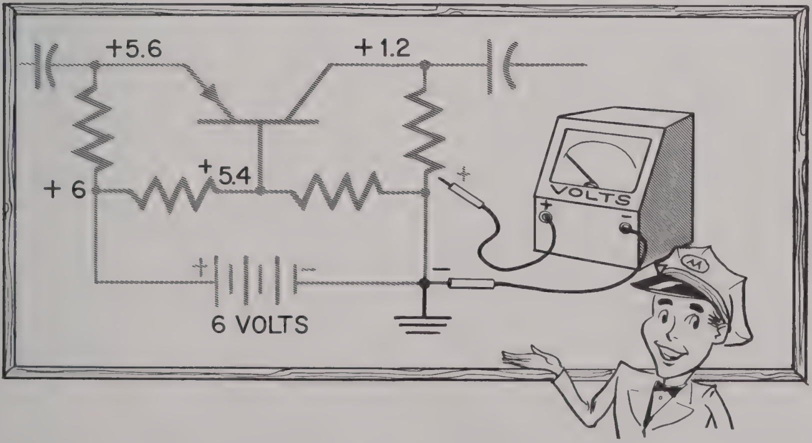
Let's take another example. Assume that the voltages of both the base and emitter are more than 10% from the recommended voltages. However, let these voltages be 1.5 volts and 1.3 volts, respectively. The forward bias is now 0.2 volt, the desired amount. This is normal even though the base and emitter voltages are considerably more than 10% from the quoted value. A further analysis of the voltages of the circuit will probably disclose that the supply voltage is higher than normal, making all the voltages comparatively higher. The circuit is probably performing normally.

In summarizing these two examples, we conclude that considerable intelligence must be exercised in analyzing the readings secured on meters. And, for these examples, we see that a knowledge of transistor operation is essential if we are to properly interpret the readings and determine which variations are acceptable and which mean "trouble." In the first example the individual voltages were actually within 10% of the rated values, but the important voltage, the emitter forward bias, was twice the desired value. In the second example the voltages were all more than 10% from the indicated values, but the forward bias was normal.

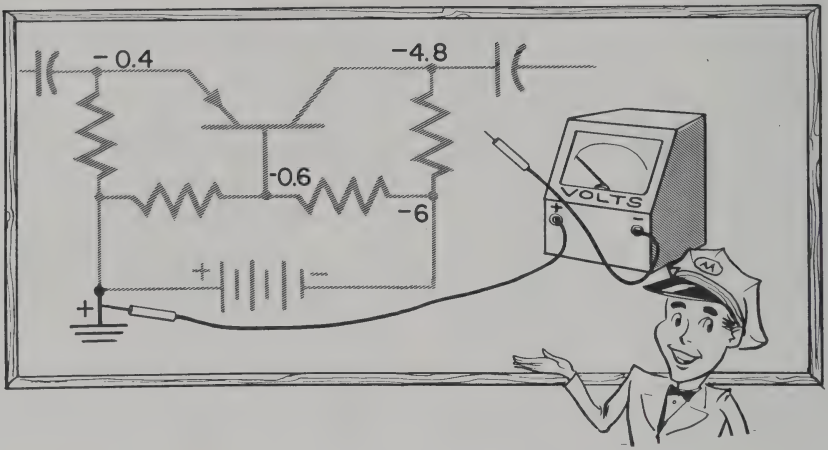
RC-Coupled Amplifier Voltages

Figure 3 gives the complete circuit of figure 2; the bypass and coupling capacitors are included. The voltages at the various circuit terminals are the same. Thus, in making voltage checks in figure 3 we follow the same procedures described for figure 2.

In figure 4 we see a very interesting variation of the circuit of figure 3. With the exception of the negative side of the power supply being grounded instead of the positive side, the circuits are exactly the same. At first glance it appears that the voltages are different, but a careful analysis dis-



When the Negative Side of the Supply is Grounded, Connect the Negative Test Lead of the Voltmeter to Ground and Take Readings with the Positive Lead.



If the Positive Side of the Supply is Grounded, Connect the Positive Test Probe to Ground and Measure Voltages with the Negative Test Lead.

closes otherwise. The voltage drops across all the resistors are the same and they also have the same polarity.

In figure 4, the negative side of the supply is grounded, and it is convenient and conventional to measure the voltages of the circuit with respect to ground. Thus, all of the voltages of figure 4 are "positive." Those in figure 3 are "negative." In figure 3 the voltages were measured with respect to the positive side of the supply (ground) while in figure 4 the voltages are measured with respect to the negative side of the supply.

Let us continue our analysis with the emitter voltage. In figure 3 the voltage between the emitter and ground is the voltage across R4; this is 1 volt. In figure 4 the voltage between the emitter and ground is not the voltage across R4, but instead is the supply voltage less the drop across R4.

With a 6-volt supply and the emitter +5 volts to ground, the drop across R4 is 1 volt. The 5 volts between emitter and ground represents the combined voltage drops across R2 and the emitter-base junction of the transistor; they are in series with R4 across the supply and together must equal the supply voltage. If we measure across R4 we should have 1 volt, with the emitter side of the resistor being negative, the same as in figure 3.

A similar analysis and comparison can be made for the base voltage of figure 4. In figure 4 the base-ground voltage is 4.8 with the base being positive. The 4.8

volts is the voltage across R2. In figure 3 the base-ground voltage is that across R3. The voltage across R3 in figure 4 is 1.2 volts, the same as in figure 3. In both circuits the base side of the resistor is negative to the lower terminal.

The bias voltage at the emitter junction is 0.2 volt with the emitter being positive to the base. Again, this is the same as figure 3. The collector voltage in figure 4 is positive with respect to ground, but it is also 3.5 volts negative with respect to the positive side of the supply, as it is in figure 3.

In summarizing our discussion of figures 3 and 4, we come to the conclusion that the only difference in the circuits is the manner of making voltage checks, not in the circuit values. In figure 3, the positive side of the supply is grounded and hence it is convenient to measure the circuit voltages with respect to ground (the positive side of the supply). In figure 4, however, the negative side of the supply is grounded and it is now more convenient to measure all of the voltages with respect to the negative side of the supply.

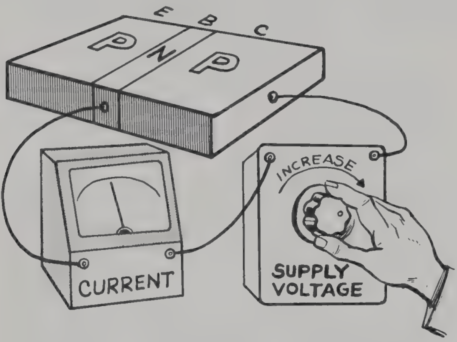
If we reverse our procedure in figure 4 and measure all of the voltages with the positive test prod of the meter connected to the ungrounded (positive) side of the supply, then all of the voltages in the circuit would correspond to those of figure 3. Conversely, if the voltages of figure 3 are taken with respect to the ungrounded (negative) side of the supply, all of the voltage will be the same as those of figure 4.

Figure 5 illustrates the voltages typical of a transformer-coupled amplifier. Compared to the RC-coupled amplifiers we have been discussing, there is no difference in the bias of the emitter junction, but the collector voltage is larger.

With the positive side of the supply grounded, all of the voltages will be negative with respect to ground and thereby the circuit is similar to figure 3. Instead of a coupling capacitor from the preceding stage, the signal is applied to the base by means of the transformer, but this does not alter the DC voltages. The forward emitter bias is 0.2 volt, the same as for figure 3. The bias is "measured" by comparing the negative voltages at the base and emitter.

The collector-ground voltage is very nearly equal to the supply voltage. Decoupling resistor R4 in the collector current path produces a small voltage drop due to the collector current through it. With 5.8 volts at the collector and with a 6-volt supply, the voltage across the resistor is only 0.2 volt.

The DC drop across the collector load, the tuned circuit, is so small that it cannot be measured by ordinary meters. Thus, we assume that there is no DC voltage loss across the coil. With the collector 5.8 volts negative to ground, the collector-base bias voltage is 4.6 volts. This is considerably higher than that of figure 3, but it does not mean that there will be any appreciable increase in collector current. Collector current is determined mainly by the emitter bias and is relatively independent of collector bias.



Increasing the Reverse Collector Bias Produces Little If Any Increase in the Collector Current.

The procedures and analysis given for the RC-coupled and transformer-coupled amplifier stages using a common emitter circuit (figures 2-5) also apply to other amplifier stages regardless of the circuit. As an example, see figure 6, a common-base amplifier.

With a negative-ground supply, the collector is connected directly to ground through the tuned circuit and, as far as DC is concerned, the collector is at ground potential. All of the other circuit terminals will be positive with respect to ground.

The forward emitter bias is the difference between the emitter and base potentials, and for the indicated values this is 0.2 volt. Because the emitter is more positive than the base, this is forward bias. The bias voltages of this circuit may be measured in the manner described for the preceding circuits.

Measuring Oscillator Voltages

In the previous examples concerning bias voltages of transistorized stages, we encountered circuits in which the forward bias of the emitter junction was a fixed value which should remain as constant as possible. There are some transistor circuits in which the operating emitter junction bias varies, and this variation is desirable and important to the operation of the stage.

In the FM communications receiver, we find that the oscillators, multipliers and limiters usually operate in this manner. We will start our discussion with oscillators.

Figure 7 shows a high-frequency, crystal-controlled oscillator circuit used in several Motorola transistorized receivers. The circuit operation is described in the preceding lesson.

If the circuit voltages are measured when the circuit is not oscillating, the voltages will be different from those given in the figure. The greatest difference will be noted in the emitter-base voltage. Without oscillation, the emitter is forward biased as we might expect, and a typical value is 0.2 volt.

An initial forward bias is necessary to make the transistor conduct. As the circuit becomes self oscillating, however, the emitter is reverse biased as indicated in the diagram. This reverse bias is similar to the Class C grid-leak bias established for most vacuum-tube oscillators, in which the grid becomes very negative to the cathode.

In the oscillator of figure 7, the base is driven very negative to the emitter during some portion of each cycle of the feedback voltage. The collector current reaches the point where it cannot increase further and, as a result, the base current increases (the same as already discussed for the limiter in a preceding lesson). This increase of base current through base resistor R2 makes the base more positive than it was originally. In fact, the DC voltage of the base is often more positive than the emitter, producing a reverse bias.

The degree or amount of voltage change taking place at the emitter junction is determined by the circuit and varies with each oscillator. Thus, some oscillators may have just enough feedback to cause oscillation and produce only a small change in the emitter bias. That is, the change may only decrease the forward emitter bias rather than cause reverse bias. Other oscillators may have sufficient feedback that the bias change at the base is sufficient to overcome the forward bias and produce a net reverse bias. We can think of these oscillators as operating in Class C.

There is a problem in measuring the reverse emitter bias for some oscillators, particularly high-frequency circuits. For figure 7, placing the leads of a meter between the emitter and base will probably stop the circuit from oscillating, so that only the initial forward bias of the stage remains. Thus, it is essential to measure the voltages of the emitter and base with respect to ground and compare the difference of the readings.

There is another factor which must be taken into consideration in measuring the voltages at the emitter in figure 7. It is very likely that the loading effect of the leads of any meter other than a vtvm will cause the stage to stop oscillating. Thus, it is important to measure the emitter voltage with a vtvm.

We must also remember that the emitter bias is not a fixed value for this oscillator circuit but, instead, it is variable and changes with both the strength of the oscillation and with the loading effect of the meter when the test leads are connected. For this particular Motorola oscillator, a metering circuit is included to provide for easy tuning (alignment). Thus, except for purposes of trouble shooting within the oscillator itself, oscillation may be checked by the reading of the test set.

Figure 8 gives the circuit of a low-frequency oscillator of a transistorized mobile two-way receiver. The analysis of the emitter bias of the oscillator in figure 7 also applies to figure 8. When the supply voltage is first applied, the stage has an initial forward bias at the emitter junction but, as soon as oscillation starts, the emitter bias swings to a reverse voltage. The amount of this reverse bias is determined to a considerable degree upon the crystal activity, and a wide variation of this voltage can be expected.

The operating frequency of the oscillator of figure 8 is considerably lower than that of figure 7, so that the circuit is not so sensitive to the effects of the meter when the test prods are connected. Either a vtvm or a 20,000 ohms/volt meter may be used to measure the reverse bias. According to the values given on the diagram, with a vtvm we should expect a reading of about 0.5 volt reverse bias.

Frequency Multiplier and Limiter Voltages

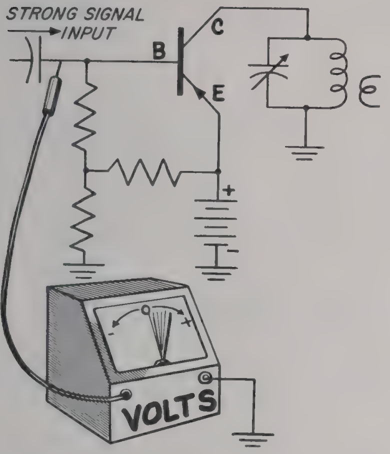
In measuring and analyzing the voltages of the frequency multiplier (following the high-frequency oscillator in the receiver) we can apply the same principles discussed in connection with oscillators.

The purpose of this stage is to multiply the frequency of the oscillator to the frequency required at the mixer (in order that the proper IF will result). This is accomplished by biasing the transistor so that the collector current occurs for only a short period of each cycle of applied voltage, and by tuning the collector circuit for the desired harmonic.

In most receivers the multiplier stage is operated in Class C; that is, the collector current occurs for less than one-half of each cycle of input voltage. Figure 9 gives a typical circuit.

The emitter is initially forward biased, but as soon as the oscillator output is applied, the base swings positive (DC) and reverse biases the emitter junction. For a given circuit, the amount of this bias change and the resulting reverse bias depends upon the signal applied from the oscillator. Thus, in making this measurement, the serviceman must be aware that this reading will vary from unit to unit, according to the "drive" from the oscillator.

The amount of harmonic output of the multiplier and hence the injection signal to the mixer is directly dependent upon the oscillator drive to the multiplier. If this injection voltage becomes too small, the mixer efficiency is



The Signal Strength at the Base of Oscillator, Limiter and Frequency Multiplier Stages May Be Measured by the Change of Base Voltage.

lowered and there is a decrease in the IF signal and a loss in sensitivity. Thus, it is important to have sufficient drive at the transistor base, as indicated by the emitter-base voltage, and the circuit must be properly aligned in order to produce maximum injection voltage at the mixer.

As far as emitter bias is concerned, the analysis of the multiplier stage applies equally well to the limiter stages of the FM receiver. The main difference of these circuits is in the collector load; the multiplier is tuned to a harmonic of the input signal while the limiter, if it is tuned, operates at the same frequency. There is another difference between these stages in that the limiter is operated so that it limits (collector current reaches maximum and cutoff) at a lower drive level than does the multiplier.

Figure 10 shows a typical limiter. The initial emitter voltage is a fraction of a volt in the forward direction, but this will vary with the strength of the incoming signal or noise voltage. This reverse emitter bias continues to increase (the base becomes more positive to the emitter) up to the point where the preceding stage reached full limiting. When this occurs, the input signal does not increase further and there will be no further change of bias voltage.

In performing service work, particularly alignment, the service technician must be aware of "saturation" and realize that once this effect takes place, the base voltage is no longer useful as a means of recording peak indications for alignment. This refers to both the voltage reading at the base, as might be recorded on a voltmeter, and to the reading provided by the test set in the next (discriminator) stage, position 5.

Let us summarize what we have said about the reverse bias at the emitter junction of the oscillator, frequency multiplier and limiter stages of the transistorized two-way communications receiver.

1. The emitter junction is forward biased initially in order

to establish the necessary current in the circuit but, as soon as the circuit starts to operate, the base voltage swings in a positive direction.

2. The amount of change taking place at the emitter junction is determined by the strength of the signal being applied. Where this signal is not very strong, the junction bias may not change very much and the emitter bias remains in the forward direction. If the signal is strong, however, the junction takes on a reverse bias, the base being positive to the emitter (for PNP transistors).

3. The base-ground voltage becomes a convenient means of measuring the amount of signal present or "activity" if we know the amount of voltage change which takes place. This may be accomplished by removing the signal and then reapplying it, noting at the same time the change of DC voltage. For most circuits, this "removal" is readily accomplished by temporarily connecting a capacitor between either the base and ground or the emitter and ground.

4. In using the voltages at the limiter base to determine the signal strength, we must realize that the signal level may be subject to limiting in the preceding stage. For this condition, the limiter will not show any further change, for the input signal to the stage cannot change.

This concludes our discussion of voltage measurements in transistorized circuits, and we are now ready to discuss ohmmeters and resistance measurements.

Ohmmeters and Transistors

Much has already been said about the use of certain types of ohmmeters in checking transistor circuits. We consider the following factors important to the serviceman in using ohmmeters for testing transistorized two-way radio equipment.

First, it has definitely been established that damage can occur to transistors through the use of some ohmmeters. This does not mean that all transistors may be damaged, for some of them are very rugged in this respect. Some transistors have definite limitations as to the voltage and current which they will withstand without damage, however, and for these transistors we need to be very careful. Following this thought further, the serviceman does not always know what "type" of transistors may be involved in every circuit, so it is well to follow certain precautions for all resistance measurements within transistor circuits.

In order to evaluate an ohmmeter for use with transistor circuits, we must know (1) the amount of internal voltage and (2) the amount of current it will deliver to a low-resistance circuit.

It is generally thought that a 4.5-volt source is safe as far as the voltages applied to transistor elements are concerned. Surface-barrier type transistors seem to have the lowest rating in this respect, and it is important to keep the voltage across these units less than 5 volts; do not use ohmmeters with 9-volt and higher supplies.

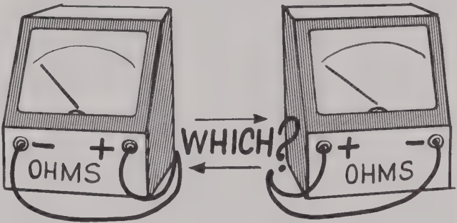
The second factor in evaluating ohmmeters for testing transistor circuits is the current the meter will deliver on its various ranges. Even though a meter may have a low-voltage internal supply, it may deliver as much as 100 mills (milliamperes) or more to a low-resistance circuit. Most vtvms allow considerable current in the external circuit on their low ohms scales.

Thus, before using any ohmmeter to test a transistor circuit, know the following:

1. The amount of internal battery voltage.
2. The amount of current which the ohmmeter will allow on its various scales.
3. It is also well to know the "polarity" of the internal source; that is, which test lead connects to the positive side of the internal battery.

Using the Ohmmeter

Even though an ohmmeter is "safe" to use in measuring or testing transistor circuits, its intelligent application requires an interpretation of the circuit being measured and the effect of the meter upon the circuit. This can be best illustrated by several examples and, for our purpose, figure 11 is convenient.



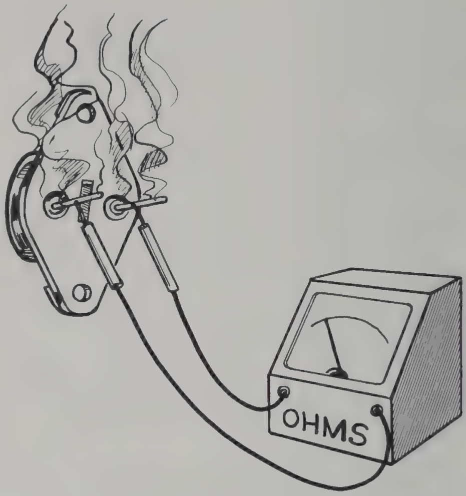
Intelligent Use of an Ohmmeter Requires the Serviceman to Know the Polarity of the Internal Battery With Respect to the Test Leads.

Let us assume that the fault has been isolated to this particular stage by some means, perhaps a stage-gain measurement and a voltage check, and the problem is now whether the transistor is defective or if one of the other parts has changed value. The first procedure is to make a resistance or continuity check of each of the parts. Let's start with the resistors.

R3 is a stabilizing resistor connected between the collector and base. The normal procedure for testing a resistor is to place the test leads across the resistor terminals and read the resistance on the meter. This is not a good idea for this circuit, and for several reasons. First, if the test leads are connected to the resistor terminals, we have connected the meter to the base and collector of the transistor.

If the test leads are placed so that the negative side of the internal battery is at the base and the positive side to the collector, the transistor junction will be forward biased and the junction will conduct current. The first consideration is that the resulting current through the meter will give a very low resistance indication which will in no manner be representative of the resistance of R3. Furthermore, if the meter furnishes sufficient current and the meter contact is maintained for some time, the transistor may be damaged. In any case, if the meter is connected to forward bias the junction, the meter reading will certainly be misleading.

Next let us suppose that we reverse the meter leads to check R3, so that the junction is reverse biased. The transistor does not conduct, so it does not affect the reading, but we must be very careful that the voltage applied to the transistor does not exceed the voltage rating of the unit. As we have already mentioned, this is particularly true of certain types of transistors.



Some Ohmmeters Deliver Considerable Current to the Circuit Under Test. This High Current May Damage Transistors.

Even though the transistor is reverse biased and does not conduct and the meter voltage is safe to apply to the transistor, this test will still give an erroneous reading. Why? For the reason that as far as DC is concerned, which is what we measure with an ohmmeter, resistor R2 is in parallel with R3 and the value noted by the ohmmeter will be the resistance of these units in parallel. The bottom of R2 connects to the right side of R3 through the ground connection and through coil L, which for all practical DC purposes has zero DC resistance.

Thus, for any connection of the ohmmeter across R3 we will find an inaccurate indication on the ohmmeter. The only way in which this resistor can be measured with reliability is to disconnect one end of the resistor from the circuit and measure directly across the resistor terminals.

A similar analysis applies to measuring R2, for resistors R2 and R3 are in parallel, as we have just seen. In addition, one end of R2 is connected directly to the base of the transistor and the other connects to the collector through the coil, so that the comments for applying voltage to the emitter junction of the transistor which were just given with respect to R3 apply equally well to the use of the meter for R2 to produce a forward bias as the collector-base junction. The only method of accurately measuring the resistance of this unit is to first disconnect one end.

Measuring the resistance of R1 with an ohmmeter presents the same type of problem encountered with R2 and R3. Meter test leads connected across R1 are also connected to the emitter and base of the transistor, and the internal voltage supply of the meter either forward or reverse biases the junction. If reverse bias is established, the reading will be accurate to the extent that the circuit is relatively free from parallel circuits which might cause wrong readings. For this particular circuit the reading across R1 may be reliable but, in order to avoid any error, it is again good to disconnect one terminal and get the correct value.

A check for continuity at coil L can also result in some doubtful readings, if we are not aware of the effect of the meter upon the transistor. With the positive side of the meter to the top of the coil and the negative test prod to ground, a continuity reading will result even though the coil is open.

The negative side of the battery connects to the base through R2 and the collector junction is forward biased and conducts. The current in the meter is limited by R2, so that the reading indicates higher than normal resistance for the coil; if the very high ohms scale of the meter is used, this difference may not even be noticed. With the test leads reversed so that the transistor does not conduct, there is also a parallel path through R2 and R3.

A unique effect can happen if we place the ohmmeter across capacitor C2 in an effort to check for a short. Suppose the test leads are connected so that the positive side of the battery is towards the emitter. The internal voltage supply can now operate like the regular supply for the stage, and the stage has both forward bias at the emitter and reverse bias at the collector. The condenser will look like a shorted unit as far as the meter indication is concerned.

In making other tests in this or similar circuits, the same principles and analysis of the effect upon the circuit by the ohmmeter will apply equally well. While the specific circuit may vary, the principles do not.

Handling Transistors--Heat Considerations

Until a few years ago, when soldering in electronic circuits the serviceman gave little thought to the amount of heat produced in the components. The advent of selenium rectifiers and printed boards brought some consideration of this factor, however, for they are both subject to damage due to overheating. This problem of heat and damage merits further thought when we introduce transistors instead of vacuum tubes.

Here We See the Basic Tools Required for Fast and Efficient Service of Transistorized Equipment Using Printed Boards.

Heat, usually from high-wattage irons, can cause damage to transistors. Or, if the equipment is left "on" during soldering, even a small rise of temperature may cause high current through the transistor and circuit components. Thus, there are several safety precautions to observe in working with transistorized equipment.

Soldering Transistor Circuits

One of the most practical methods of minimizing the temperature rise of a transistor while soldering is to hold the lead of the transistor with a long nose pliers. The pliers must be between the terminal being soldered and the transistor body, and reasonably close to the soldered terminal. (Any heat which gets past the pliers will be dissipated in the wire length to the transistor.)

Do not allow the iron to remain on the terminal while the iron is heating. It is much better to wait until the iron is hot and then place the iron on the terminal for a minimum length of time--only long enough to complete the job. Where a considerable amount of time is needed to complete a job, it is best to occasionally remove the iron, let the parts cool off, and then proceed.

The transistors in most two-way equipment are soldered directly into the circuit rather than use a socket. This allows for a more permanent electrical connection and avoids one possible source of poor contacts when metallic surfaces oxidize with time. In addition, soldering allows for a better mechanical construction than is afforded by sockets, and this is another very important factor in two-way equipment.

If a socket is used, it is important to make sure that heat due to soldering does not reach the transistor through the socket terminals. It is best to remove the transistor before soldering.

The fact that the outer case of a transistor is held in a clamp does not mean that the transistor is less free from the effects of overheating due to soldering of the leads. Except for power transistors, the case of the transistor is well insulated, heat-wise as well as electrically, from the operating part of the transistor and does not carry the heat away from the unit fast enough to be helpful in this respect. Some leads of transistors are connected to internal shields and do not transfer heat directly to the active elements of the transistor. Therefore, soldering these leads does not readily cause damage.

For power transistors, where the collector is usually in direct metallic contact with the case, heat is quickly transferred to the case and dissipated into the chassis or heat sink on which the transistor is mounted. Such transistors are less likely to be damaged by soldering. In addition, they are larger than other transistors and heat more slowly. Even for these units, however, it is well to avoid overheating due to excessive soldering time.

One important factor in the heat problem associated with soldering around transistors is the rating of the iron. Special low-wattage irons are available, and these are rated between 25 and 40 watts. Also, low-melting solder--called "60/40" because of its relative proportion of tin and lead--is helpful in completing a soldering job with a minimum of heat transfer.[1]

Parts Substitution

One good policy which will avoid many troubles is to use the exact replacement part recommended by the manufacturer of the equipment whenever it is necessary to replace a defective component. The only exception to this rule is the case where some equipment must be placed in operation immediately and the exact replacement is not on hand. Even then, it is best to secure the correct part and replace the substitute in the equipment as soon as possible.

There are some components in any equipment which are not so critical that a satisfactory replacement part cannot be used without sacrificing the operation of the unit. On the other hand, there are some parts which are very critical to the point that substitute

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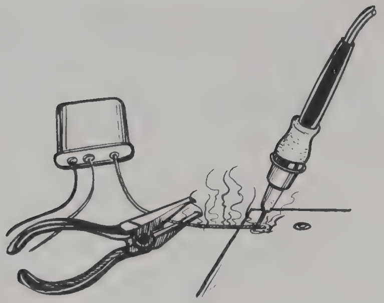
[1] See "Printed Circuit Service Tips," reference S-8D



A Pliers Holding the Lead Between the Transistor and the Soldered Connection Prevents Overheating of the Transistor Junctions.

components, although they seem to be about the same as the original, do not give optimum service and operation. This is particularly true of equipment found in two-way systems.

Also, in making replacements, parts values are often very critical and components which are "near" the correct value are not permitted. Too many undesirable characteristics may occur if the wrong parts are used. Sometimes a part which seemingly is unimportant can cause unexpected problems. For instance, a wrong-size resistor in the squelch circuit can reduce the squelch sensitivity to the point that the squelch will not open for weak signals; the receiver does not reproduce the incoming messages.

As another example of improper parts substitution, a capacitor may have the same capacitance, voltage rating and tolerance, but it may not be a good bypass at the high frequencies involved. Or the capacitor may change value with temperature changes and detune circuits.

The same reasoning applies to almost all of the parts in this specialized equipment, so that the logic of using "factory" replacement parts is obvious. Even more critical than capacitors and resistors, substitute transistors can cause a lot of trouble. Although not an infallible safeguard, it is well to secure exact replacement transistors and not take a chance on "substitutes."

Even transistors of the same type have considerable variation from one unit to the next. For this reason, transistors of the same type number may be further graded according to their electrical characteristics; they are identified by additional color dots. Where such transistors are specified by the manufacturer, substitutes should never be used.

Almost all stages regardless of their frequency of operation or power level can produce poor operation if the transistors are not replaced by suitable units. Even low-level audio transistors may cause trouble if they are not reasonably identical to the original part. For example, consider the transistor in the preamplifier stage of the microphone. Here the output level of the microphone is very important.

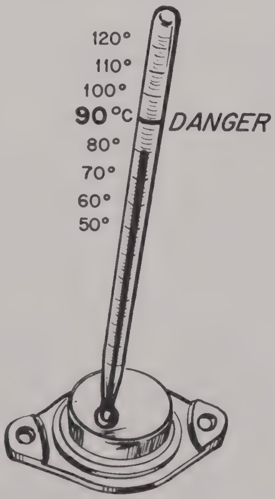
If the microphone amplifier output is too high, all modulating voltages reaching the transmitter will drive the IDC circuit into full clip and cause unnecessary distortion. On the other hand, a transistor with too little gain will produce a weak signal to the transmitter and normal voices will not produce sufficient modulation to provide good system response.

For proper operation of the transmitter, it is important that the microphone output be within certain minimum and maximum limits; substituting the wrong transistor in the microphone may produce an output voltage which is outside of these limits.

Many of the parts associated with the transistorized receiver are different from those to which we have become accustomed. Perhaps the first noted difference is the small size of most of the resistors. Due to the small currents involved in transistors and the relative low impedances of the transistor input and output, small resistance values are paramount. This all adds up to low wattage dissipation in the resistors; small units suffice and invite miniaturization.

Another noticeable characteristic of transistorized receivers is the capacitance and voltage ratings of the capacitors. Due to the low voltage applied, the usual high-voltage capacitors are no longer required. This means that the units may be made considerably smaller. However, due to the low impedances of many of the circuits, the reactance of many of these capacitors must be very low to provide satisfactory bypassing and coupling. As a result, many of the circuit capacitors which before have had comparatively small capacitance are now in the "electrolytic class." That is, the required capacitance is so large that an electrolytic is the only practical answer if the size is to be kept small. Specially developed electrolytic capacitors have been developed for this type of service. These are made from tantalum metal and are generally referred to as "tantalums." They are relatively expensive but provide a means of miniaturization.

Tantalum capacitors are sensitive to reverse polarity. Therefore, when making replacements



Transistors Can Be Damaged by Excessive Heat.

be sure to avoid applying reverse voltage to these units. If the unit should be damaged by reverse polarity, it does not "reform" as do regular electrolytics and the unit will not perform as intended. There are specially built tantalums which will withstand reverse polarity, but they are more expensive and are used only where it is essential to do so. These are the "foil" type tantalums.

Most low-voltage, high-capacitance electrolytics exhibit a greater amount of leakage current than found in higher voltage units. Using a 6-volt supply, such as found in most bench-type testers, a leakage of at least 10 microamperes is permissible after the unit has had a chance to reform.

Printed Boards and Modular Construction

Printed boards are not exclusive to transistor circuitry, for vacuum-tube equipment such as TV receivers, test equipment, etc., have used printed boards rather extensively in the last several years. Besides its obvious advantage of reducing the cost of production, printed board construction offers other advantages. Very important is the reduction of wiring within the equipment, and there is no service problem of lead dressing.

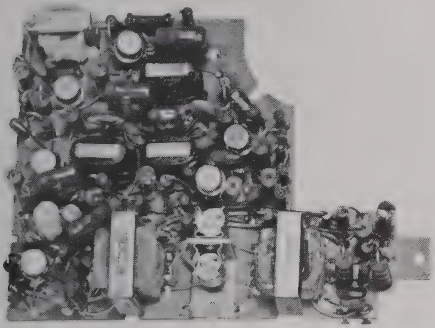
Transistors, due to their small size and weight, offer greater opportunities for compact equipment in conjunction with printed board techniques, to the point that small modular construction has allowed extreme compactness and miniaturization of what was once large, heavy equipment. A good example of this is the pocket-size communications receivers having extremely good sensitivity.

Because printed boards are almost inherently a part of transistorization, this lesson dealing with the service of such equipment must include printed board service techniques.

One of the first problems encountered by the serviceman when troubleshooting transistorized equipment is the location of the various parts. In many cases the serviceman looks at the bottom of the board which has a lot of printed circuits. In order to locate the various circuit terminals, full use must be made of the service material which is found in the instruction manual.

Perhaps the most useful service information is the wiring diagram with respect to the printed board and the parts which are connected to the various terminals. An example of such a diagram is shown in figure 12. This is the wiring of a Motorola pocket receiver using printed boards and modular construction. This, used in connection with the section layout at the lower right of the figure and the schematic allows the serviceman to readily locate all the circuit terminals and troubleshoot the receiver.

As an example of what can be accomplished by this material, suppose that we wish to make a quick check of the first audio stage, for we suspect from the operation that the receiver is squelched at all times and is not opening when a signal comes in. This is also evident from the fact that the complete rotation of the squelch control does not open the receiver and allow the noise to be heard even when there is no signal.



Here We See the Audio and Squelch "Circuit Board" of a Typical Mobile Two-Way Receiver.

From the sketch at the lower right in figure 12, we see that the audio amplifier is in the "L" shaped module, and from the schematic diagram, not shown here, we find that the base of Q12, the first audio amplifier, should have +2 volts when squelched and -0.3 volts when unsquelched. In figure 12 we locate the portion of the board that connects to the base of Q12 and find that the voltage is always about 2 volts positive regardless of the position of the squelch control. This confirms our conviction about the nature of the trouble in the receiver and may now continue to check further on the squelch circuitry. We follow the same general procedure in locating the various circuit terminals and in making voltage tests.

Repair of Printed Boards

Proper soldering techniques are essential to the maintenance of printed boards, and much has already been published on this subject. We will only attempt to summarize at this time what has already been said. A soldering iron of about 40 watts is recommended for this procedure and 60/40 type solder with a little silver added is best.

One trouble which might be encountered with printed boards is fine, hair-like cracks which occur but are not discernible with normal viewing. A good lighting system is essential, and a magnifying glass is also useful. Commercial units incorporating both these features in a single assembly are available. Hairline cracks are often detected by making voltage or resistance tests, in addition to a visual inspection.

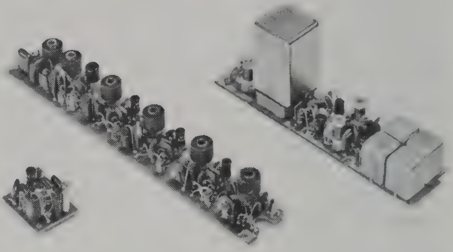
Breaks in the plating are repaired by means of a jumper wire across the break. Where the board as well as the plating is cracked, follow the suggested procedure included in Reference S-8D.

As shown in figure 12, many of the stages are built as a small module. Each assembly is extremely small and, in cases where time is an all important factor, it may not be wise to perform troubleshooting and repair work within any one module. Because they are so small and incorporate but a few parts, it may be more efficient to replace the complete module known to be bad rather than spend the additional time required to further isolate the fault. The defective module can be repaired at some future time and at the convenience of the technician.[2]

Servicing Transistorized Power Supplies

For the purpose of this lesson, we shall not be concerned with the manner in which the switch type transistor power supply operates; instead, we shall determine the proper procedures to follow in servicing these supplies. There are several operating characteristics of these supplies which make it convenient for the service technician to analyze the nature and location of the trouble. We shall look at these characteristics carefully.

First, the output voltages of the supply varies with the load or amount of power delivered by the supply. The greater the load current, the lower the output voltage. The higher current through the various components produces larger voltage drops, causing a lower voltage at the output terminals. (This characteristic is common to all unregulated power supplies.) Thus, by carefully observing the output voltage, it is possible to estimate the relative load on the supply.



Starting at the Left, We See the Low-Frequency Oscillator, 455-KC IF and High-Frequency Oscillator-Multiplier Sections of a Transistorized Receiver.

Another important factor, and this one is unique to this switch type of power supply we are talking about, is the change in the operating frequency as the load increases. As the load increases, the frequency decreases. If the load increases beyond a certain point, the switching action stops altogether and there is no output voltage.

Also, where the radio is operated in a relatively quiet location, there is a slight "singing" sound heard from the power transformer; according to the "pitch" of this sound, which is the operating frequency, we can deduce the load on the supply.

The fuses also help to determine the nature of the trouble. For example, if a fuse burns out as soon as the set is turned on, we have a different problem than if the fuse burns out only intermittently, or only when the transmitter is being used.

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[2] See references S-8A, S-8B, S-8C and S-8D.

These are the things we will make use of in troubleshooting the transistorized power supply. We will start our discussion by assuming that some trouble has been traced to the supply--at least it seems to be in the supply--and the fuses blow as soon as they are replaced. The radio is being operated on the test bench in an effort to determine the specific trouble. Figure 13 gives the schematic of a typical transistorized supply which operates either the receiver or the transmitter of the two-way radio set. This supply was chosen because of the possibility of different sources of trouble, compared with the power supply used with the two-way radio having a transistorized receiver, in which case the power supply operates only during transmit.

Fuses Blow

For the symptom of continuous blowing of power supply fuse F1 (not F2, the fuse to the receiver and transmitter filaments, etc.), it is probable that a transistor in the power supply is defective. Only a direct short in the primary circuit will continue to blow fuses and, in almost every instance, this will be a transistor. Conversely, if the fuse does not blow, it is not likely that the transistors are bad. Thus, the fuse to the transistor switch circuit, F1 in the diagram, is a very good indication of the condition of the transistors.

If the fuse is blown it is well to try a new one, before doing any other troubleshooting, for occasionally a fuse will blow without anything being wrong in the supply. With a new fuse installed, the unit can be put back into operation. Where fuses continue to blow, however, we can be reasonably sure that one of the transistors is bad and requires replacement. Although the transformer could cause the same symptom, it is not often likely to be the source of trouble.

Testing Transistors

The transistors found in power supply switching circuits are the power transistor type and require a power transistor tester. If one is not available, a quick check on the transistors can be made by following the procedure shown in figure 14. Here an ohmmeter--any kind is okay for power transistors--is connected with the positive side of its internal battery to the emitter and the other meter test lead to the collector.

The meter adjustment should be set so that the pointer is somewhere near the middle of the meter dial. The base is then alternately shorted to the emitter and collector and the changes of meter current observed. With the base to the emitter, the current should decrease; when the base is connected to the collector, the current increases.

We need not be concerned with the amount of change in determining the condition of the transistor, for it has been found by experience that these transistors will be completely bad, or they will be okay to use in the supply. Thus, if the meter readings increase and decrease, the transistor is probably normal and does not require replacement. If the changes are not as indicated, however, the transistor is defective, and a new unit should be installed.

It is not essential that the transistors in a power supply be matched. As long as they check near normal, they will operate satisfactorily.

Replacing Transistors

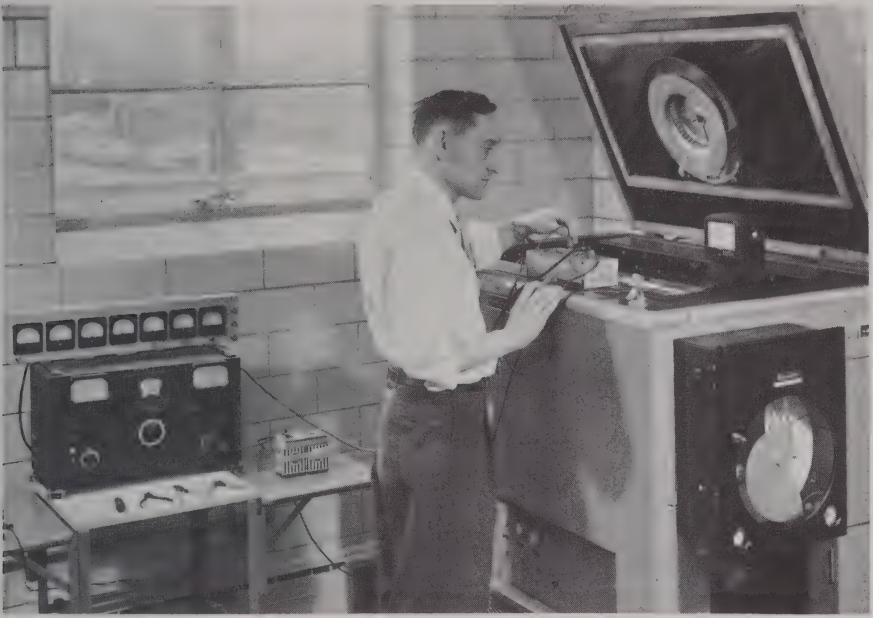
In replacing the transistors of many power supplies, the transistors are electrically insulated from the heat sink by thin mica washers. This allows for operation from either a positive or a negative grounded electrical system in the vehicle. At the same time that the transistors are isolated from the heat sink, a special lubricant is used to maintain good heat transfer from the transistor to the sink. Thus, always be sure that the transistors are not shorted to the heat sink, particularly after making a replacement.

Also, when a transistor is replaced, it is well to make a check on the primary circuit before turning on the supply. This is particularly true of the base circuit of each transistor. If the base circuit happens to be shorted to ground, the transistor will probably burn out as soon as the supply is turned on. The parts within the dashed lines in figure 13 are located on the front panel of the radio assembly and should be checked carefully for a short. This also applies to the cabling between the power supply chassis and the transistors.

Operational Test

If a transistor has been replaced and the primary circuit has been checked for a short, the base circuit of the transistor in particular, it is permissible to turn on the power supply for a "quick check." That is, it is okay to turn on the supply and determine if the switch circuit starts, and listen to the frequency of the switch operation. This quick check will not allow enough heat to burn out the transistor even though the secondary is overloaded. Of course, if the supply is left on for too long a time, there may still be something in the power supply or the load which will cause the transistors to go bad due to excessive heating.

Following this thought, every time a supply is turned on it should be an automatic procedure for the serviceman to listen to the "sound" of the switch circuit. If the frequency is too low, it is not wise to let the supply on for any length of time; leave it on only long enough to make quick tests. If the frequency, on the other hand, is near normal. the load cannot be excessive to the point that short-term operation will cause damage. There is now sufficient time to make voltage checks on the equip-



In Designing Transistorized Equipment, It is Important to Check for Operation at All Temperatures.

ment and perform what other service work that must be done while the supply is operating.

If the serviceman is to utilize the operational frequency of the power supply as a means of judging the operation of a supply, it is necessary that he know the sound of these supplies under normal operation. Without this pre-experience, he will not be capable of reaching quick, valid conclusions.

It is always good to check the supply on both standby and transmit operation, for there is always the possibility that the trouble is in the transmit section of the supply or in the transmitter itself rather than in the receiver or the low-voltage section of the supply.

Overloads and Transistor Burnouts

There is one main danger of operating transistor power supplies when they are overloaded. We already know that the operating frequency decreases with an increase of load. We found further that the switch circuit will even stop operating if the overload is too great. There is a dangerous point where the overload is not sufficient to cause the switch to stop operating, but at the same time is sufficient to cause the transistors to be damaged by excessive heating if the supply continues to operate. Thus, do not continue to operate the overloaded transistor supply even though the switch circuit operates.

Too heavy an overload prevents the circuit from operating; under this condition, the transistors do not draw any appreciable amount of current and will not be damaged if the supply is left on. Troubles for this type of inoperation are almost always complete or near-complete shorts in the secondary circuits (or in the receiver and transmitter), and may often be found with the use of an ohmmeter. Again it is advisable to compare the operation on both the receiver and transmit position. If the short is evidenced for both positions, the fault is probably internal to the supply.

A short on only the transmit or receiver position may indicate a short in the transmitter or receiver rather than inside the supply. Because the low-voltage section of this particular supply is used for both the receive and transmit, a short here will show up on both positions. On the other hand, a short in the high-voltage section of the supply will be evidenced only when the equipment is operated in transmit. Here the short could be internal to the supply or it might be in the transmitter; a further check to isolate the location of the trouble will be necessary. For the purpose of this lesson, however, we will assume that the troubles are all internal to the supply.

Shorts in the Filter Sections

Neglecting shorts in the wiring...which must be considered as a possible source of trouble in actual equipment...there are only two likely points where shorts might occur inside the power supply, namely the filter capacitors and the rectifiers.

Electrolytics are more likely to have a partial short than a complete short. That is, they develop a leakage which allows a higher than normal current through them, but at the same time, they do not look like a complete short (zero resistance). Because they are not often completely shorted, filter condensers do not normally stop the supply from operating, but merely cause a reduction in operating frequency and lower output voltages. These partially shorted capacitors are often found by any or all of the following:

Here We See a Complete Stage (Module) of a Modern Pocket-Size Receiver.

1. The capacitor feels "hot" when touched.
2. They start to "leak" or show other physical signs of being bad.
3. Measure with a capacitor bridge for shorts (power factor).
4. Replace and compare the operation. (The wiring to the capacitor may be disconnected for a quick check.)

Although electrolytics may "open," there will not be any evidence of this as far as the supply parts overheating or the fuses are concerned; there will be no "short" to cause any damage. Instead, the inadequate filtering will show up in the operation of either or both the receiver and the transmitter.

Rectifiers

Power supplies in two-way mobile radio equipment may use either selenium or silicon rectifiers. The characteristics of these two units vary considerably as far as typical troubles are concerned. Selenium diodes are more likely to develop leakages rather than complete shorts, so that they look like a medium-low resistance. The resulting additional current causes a lower output voltage. When the output voltage at the rectifier is low, it may be well to install new rectifiers and compare the results.

Silicon rectifiers, by contrast, are most likely to short completely so that they stop the circuit from operating--the switch will not function. Shorted rectifiers are readily found by a resistance check of the rectifiers, measuring in both directions. These units are often mounted on spring clips and can be removed as easily as a fuse. A good rectifier will usually show less than 100 ohms in one direction and somewhere around 1000 times this resistance in the other direction.

Output Voltages

The output voltages of the power supply are convenient in evaluating the operation of the supply. This is particularly true when this information is used with the "sound" or operating frequency. If the output voltage is within 10 or possibly 15% of its rated value, it is possible that the supply is operating normally. We must always remember that these voltages vary with the degree of loading; the transmitter loading, in particular, varies considerably with the transmitter adjustments.

If the output voltages are too low, do not turn the supply on for any great length of time. It is possible to burn out a transistor by continued excessive current. It is probably okay to turn the supply on for short intervals in order to make tests, but do not let the transistors get too hot. This is a major source of transistor burnouts.

The output voltages also vary considerably with the primary voltage. In the vehicle, the primary voltage should be somewhere near 13.5 volts, if the output voltages are to be correct. This takes into consideration that for transmit there will be about 1-volt drop across the cables, so that the voltage at the power supply input is about 12.5 volts. There is less cable drop during standby, so the voltage to the supply should be around 13.5 volts during standby. These quoted voltage values will vary considerably with different models and types of two-way equipment.

Inoperative Switch

If the switch circuit refuses to operate, suspect a defective primary circuit, a bad transistor, or a direct short across the secondary. Make a check of the transistors as already suggested, and check the primary circuit. Do not overlook the possibility of a defective fuse or a poor connection.

In order to check the secondary circuits for a short, it is permissible to remove one end of the silicon rectifiers from their sockets, or remove the connections of the transformer secondary if the rectifiers are not in clips. This removes all the load from the secondary winding and the switch circuit should work provided the primary is okay, the transistors are good, and the transformer is normal. The switch frequency will be rather high for this test, for there is no load.

Since the transformer is the least likely source of trouble, it should be the last unit which we suspect. It is designed for operation at a high frequency and should not be tested by applying a known 60-cycle AC voltage to one winding and measuring the other voltages. In fact, except for a general continuity test of the windings and a resistance check for a short between windings, there is little that can be done "in the field" about testing the transformer. The only reliable method is to try another transformer and compare the results.

Test Bench Operation of Transistorized Receivers

One problem arises in connection with the operation of transistorized receivers on the test bench, where the power source is usually an AC operated supply. The supply found in the average service shop is satisfactory for the vacuum-tube type receiver, but there is a problem of inadequate filtering for the operation of transistorized receivers.

The average AC operated supply has too much ripple (due to insufficient filtering) in the output to provide normal operation of the transistorized receiver. As a result, there is a predominant hum in the speaker and the quieting measurements of the receiver are affected. There are two practical solutions to this problem. First, a regular 12-volt storage battery may be placed across the power supply output terminals. Second, additional filtering may be added.

A storage battery across the output terminals acts like a very large capacitance and in most cases provides the additional filtering needed to restore normal operation. The problem of maintaining the battery at full charge is readily solved by allowing the power supply to act like a charger for the battery.

The second procedure of adding a filter to the primary power supply is a very satisfactory solution to the problem, provided the filter section is adequate. This, in turn, is determined to some extent by the amount of initial filtering in the supply. Usually the combination of a heavy choke (capable of handling the current drain of the equipment) and a large capacitor (at the output) will provide the necessary filtering. The capacitor is usually a 10,000-25,000 mfd unit rated around 20 volts DC and a DC surge voltage rating of about 30-40 volts. The filter capacitance in the power supply acts like an input capacitance to the added filter section. Added capacitance at this point will improve the filtering and the regulation, but it is not necessary if the supply has a reasonable amount of internal capacitance. The circuit of a typical filter section of this type is shown in figure 15.

While an additional filter is added to the power supply for bench operation of the transistorized receiver, the operation of the transmitter does not require the extra filter. Furthermore, the DC drop across the choke during transmit may produce a low voltage to the transmitter. A higher output voltage is possible by shorting a heavy wire across the choke terminals during transmit operation. This will also improve the regulation, for, unless the choke has an exceedingly low internal resistance, the added drop produces a poorly regulated output voltage.

Summary

Let us summarize briefly what has been said about troubleshooting the power supply:

1. In working with the transistorized switch type of power supply, we make use of the output voltages, the frequency of operation as determined by the "sound," and the fuses.

2. If replacement fuses also burn out, one (or more) of the transistors is probably defective and must be replaced.

3. Transistors may be tested with a regular tester or by the simple method shown in figure 14.

4. Replacement transistors must be electrically insulated from

the heat sink in some applications, but a good thermal contact is maintained by a special silicone grease on the washers.

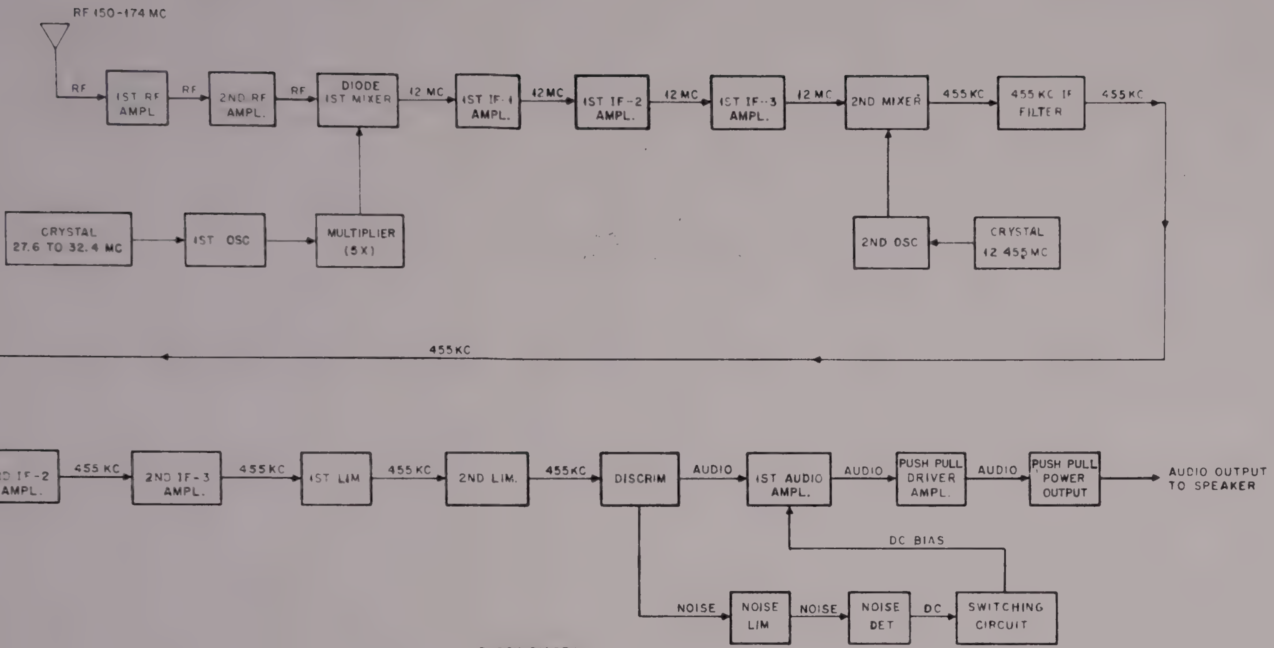
5. Transistors should be tested for a short to the heat sink, and the base circuit should be similarly checked before operating a supply with a new transistor.

6. A heavy load will stop the switch from operating. A heavy load, but not a complete short, causes the switch circuit to "slow down" in frequency and this change can be heard. The output voltage of the supply also varies in the same manner as the operating frequency.

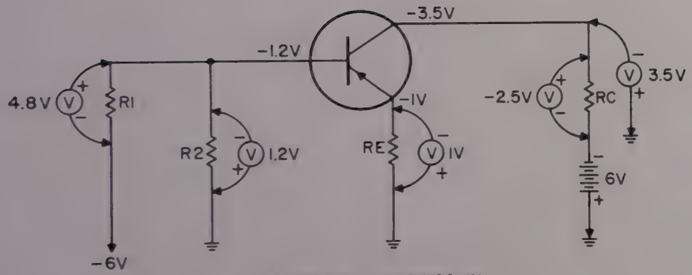
7. Electrolytic capacitors and selenium rectifiers may become leaky and overload the supply. For an overloaded supply, do not leave the supply on for long periods as this can cause the transistors to overheat and burn out.

8. Silicon rectifiers are more likely to short completely rather than develop some leakage. Silicons may be checked by their front-to-back resistance.

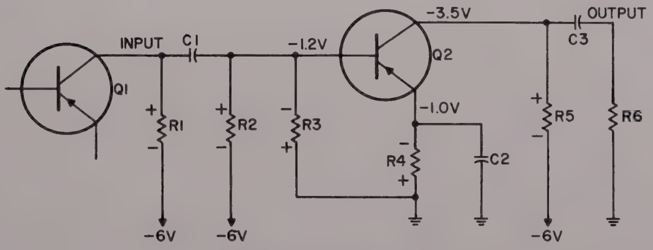
STUDENT NOTES



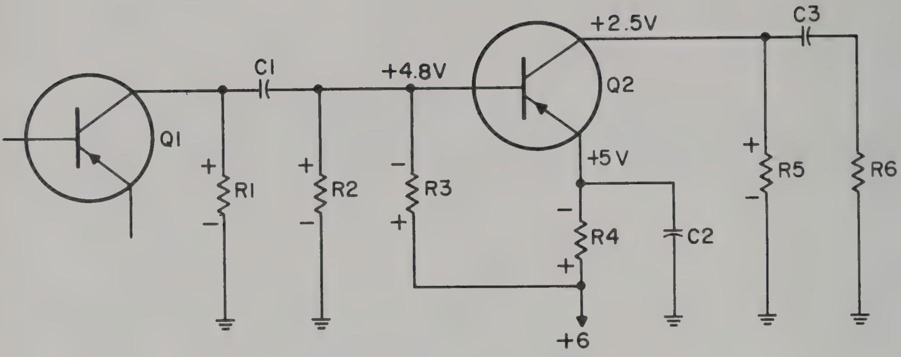
BLOCK DIAGRAM
FIGURE 1



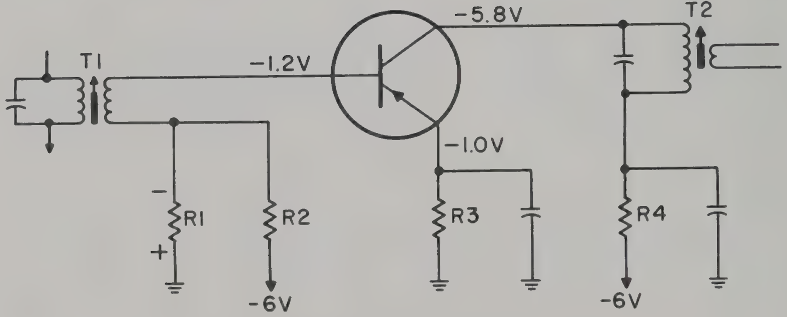
VOLTMETER READINGS IN TRANSISTOR CIRCUITS
FIGURE 2



RC-COUPLED AMPLIFIER
FIGURE 3



RC-COUPLED AMPLIFIER
FIGURE 4



TRANSFORMER COUPLING
FIGURE 5

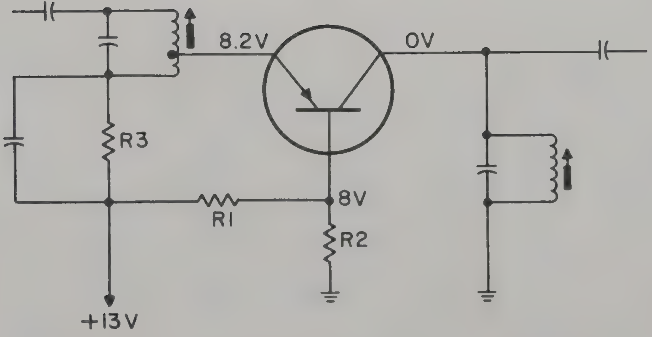
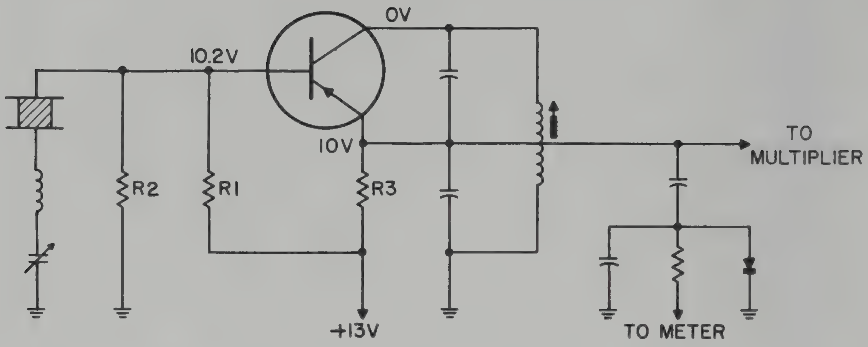
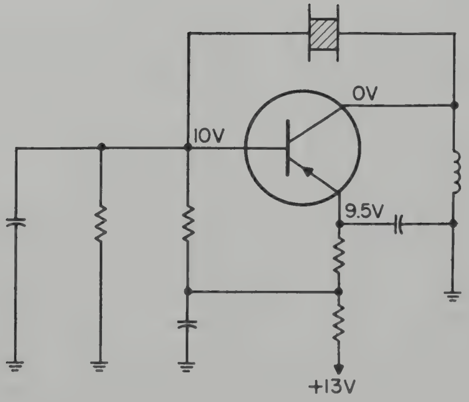


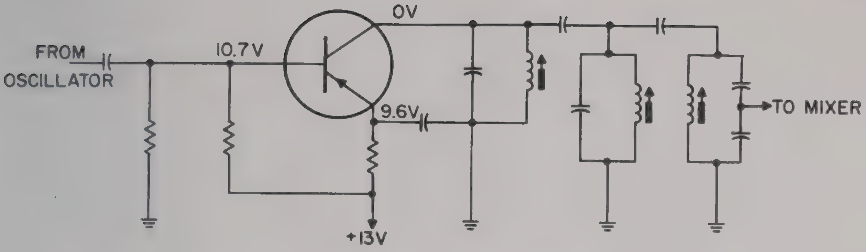
FIGURE 6



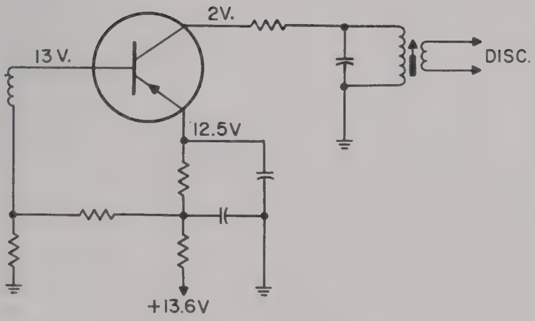
HIGH-FREQUENCY OSCILLATOR
TWO-WAY COMMUNICATIONS RECEIVER
FIGURE 7



LOW-FREQUENCY OSCILLATOR
TWO-WAY COMMUNICATIONS RECEIVER
FIGURE 8



FREQUENCY MULTIPLIER
TWO-WAY COMMUNICATIONS RECEIVER
FIGURE 9



455-KC LIMITER
FIGURE 10

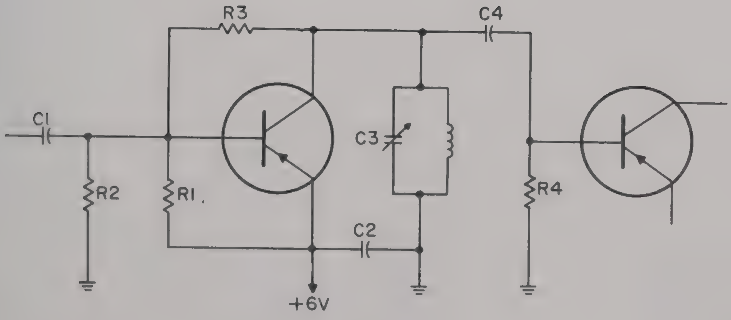
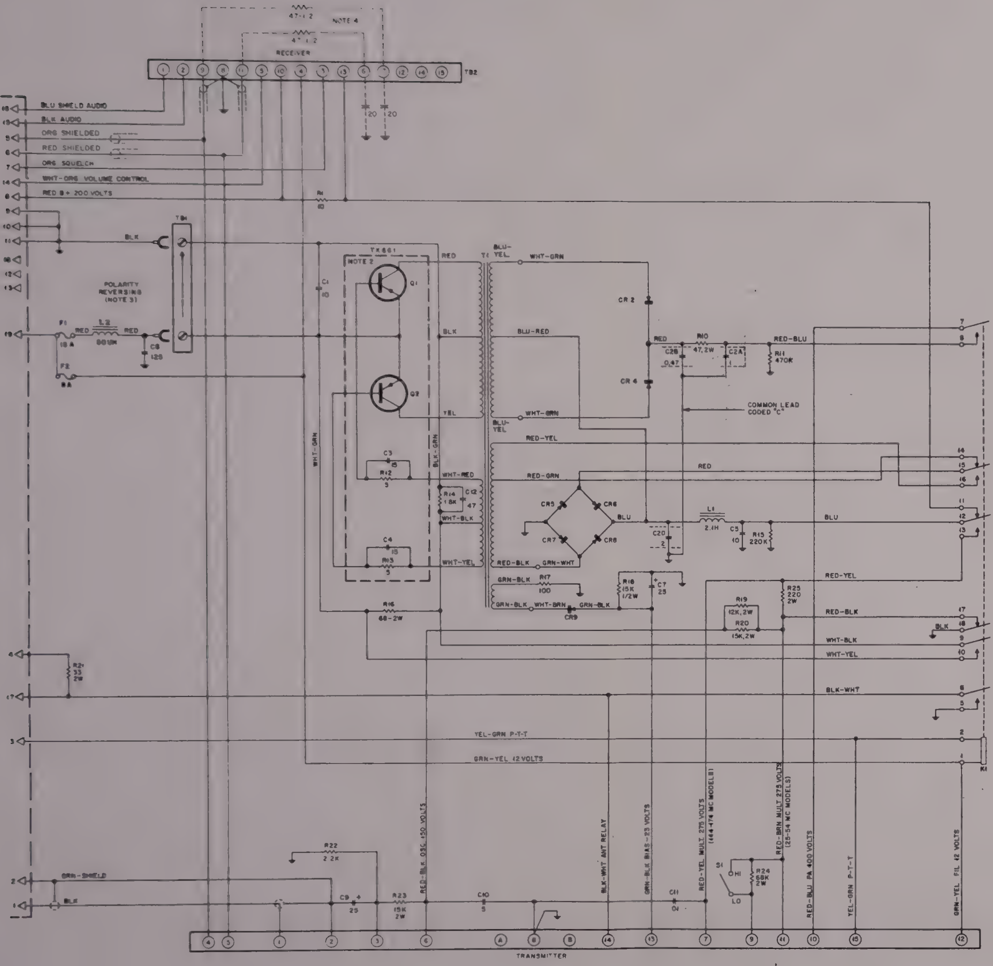
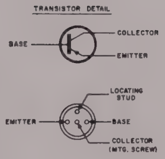


FIGURE 11



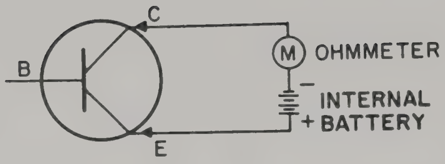


NOTES:

1. UNLESS OTHERWISE SPECIFIED:
   ALL RESISTOR VALUES ARE IN OHMS, ±10%, 1 WATT
   K =1000 OHMS.
   ALL CAPACITOR VALUES ARE IN MICROFARADS.
2. COMPONENTS ENCLOSED IN DASHED LINES ARE LOCATED IN FRONT PANEL.
3. POLARITY REVERSING TERMINALS SHOWN FOR NEGATIVE BATTERY GROUND (BLK TERMINAL TO ARROW). FOR POSITIVE BATTERY GROUND, REVERSE THE TWO TERMINALS (RED LEAD TO ARROW).
4. TLN6155A RCVR. FILTER KIT IS P/O 2-FREQ. RADIO SET ONLY. REFER TO INTERCABLING DIAGRAM FOR PARTS IDENTIFICATION.

TRANSISTOR "SWITCH" POWER SUPPLY

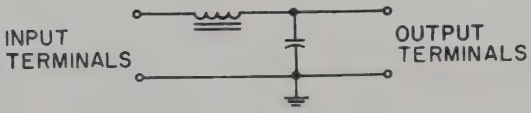
FIGURE 42



TEST CIRCUIT FOR POWER TRANSISTORS

1. CONNECT OHMMETER WITH POSITIVE SIDE OF INTERNAL BATTERY TO THE EMITTER AND NEGATIVE TO THE COLLECTOR.
2. USE SUITABLE SCALE AND ADJUST FOR CENTER-SCALE READING.
3. CONNECT BASE TO EMITTER = READING SHOULD DECREASE.
4. CONNECT BASE TO COLLECTOR = READING SHOULD INCREASE.

FIGURE 13



POWER SUPPLY FILTER SECTION
FIGURE 14

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Name ______________________ Student No. ______

Street ______________ Zone ____ Date ______

City ______________ State ______ Grade ______

EXAMINATION, LESSON SA-8

1. From which of the following voltages would you expect a completely transistorized receiver to operate? (Choose only one answer.)
   A. 110 volts, DC ____ B. 110 volts, AC ____ C. 110 volts, AC or DC ____
   D. 12 volts, DC ____ E. 110 volts and 12 volts DC ____ F. None of these ____

2. Transistor voltages should be measured (directly between the elements) (at each element with respect to ground). If the positive side of the supply is grounded, all of the measured voltages will be (positive) (negative) to ground.

3. In using vtvm's to test transistor circuit voltages, use the (highest range) (lowest range) on which a reading is secured. For lower sensitivity instruments, it is important to use the (highest range) (lowest range).

4. Figure A shows a typical transistor amplifier stage. The voltages shown are those measured by the meters in the indicated positions.
   A. Indicate the polarity of the test leads for each meter shown.
   B. What is the value of the forward bias at the emitter junction? ____volts.

5. Referring to figure A,
   A. What is the voltage across R1? 22 volts ____ 10 volts ____ 0.2 volt ____ 2 volts ____
   B. What is the voltage across RE? 22.2 volts ____ 1.8 volts ____ 0 volts ____ 12 volts ____

6. During normal operation, which of the following stages might have a reverse emitter junction bias?
   RF amplifier ____ Oscillator ____ Limiter ____ Multiplier ____ Audio output stage ____ First IF Amplifier ____

7. Figure B shows a typical limiter stage in a two-way FM receiver. Indicate the correct manner of connecting a voltmeter in the circuit to show the amount of limiting due to the incoming signal. Be sure to show the meter polarity.

8. Which of the following tests indicate if a transistorized oscillator stage is functioning? (More than one answer is correct.)
   Measure the reverse bias between the collector and base. ____ Measure the injection voltage at the mixer. ____
   Measure the emitter current. ____ Measure the reverse bias between the emitter and base. ____

9. Which two factors about an ohmmeter can cause damage to a transistor circuit?
   Ohmmeter battery voltage is too high. ____
   Test leads connected to circuit in the wrong direction. ____
   Ohmmeter supplies too much current to the circuit. ____
   Ohmmeter does not have a range for measuring extremely low resistance values. ____

10. In figure C, which of the following tests provides the most accurate measurement of the resistance of the emitter resistor? (Choose only one answer).
    Place the positive side of the meter to the emitter and the negative side to ground. ____
    Place the negative side of the meter to the emitter and the positive side to ground. ____
    Remove one side of the resistor from the circuit and measure across the resistor terminals. ____
    Measure the resistance of the parallel branches and subtract the resistance of the resistors in parallel. ____

FIGURE A

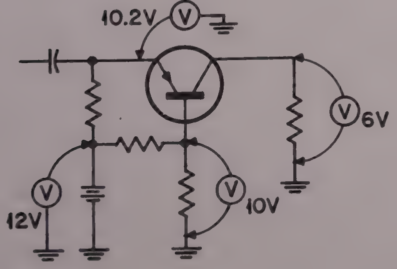


FIGURE B

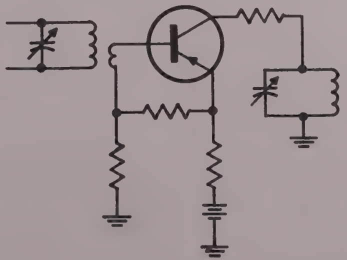
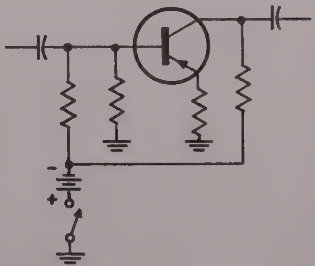


FIGURE C



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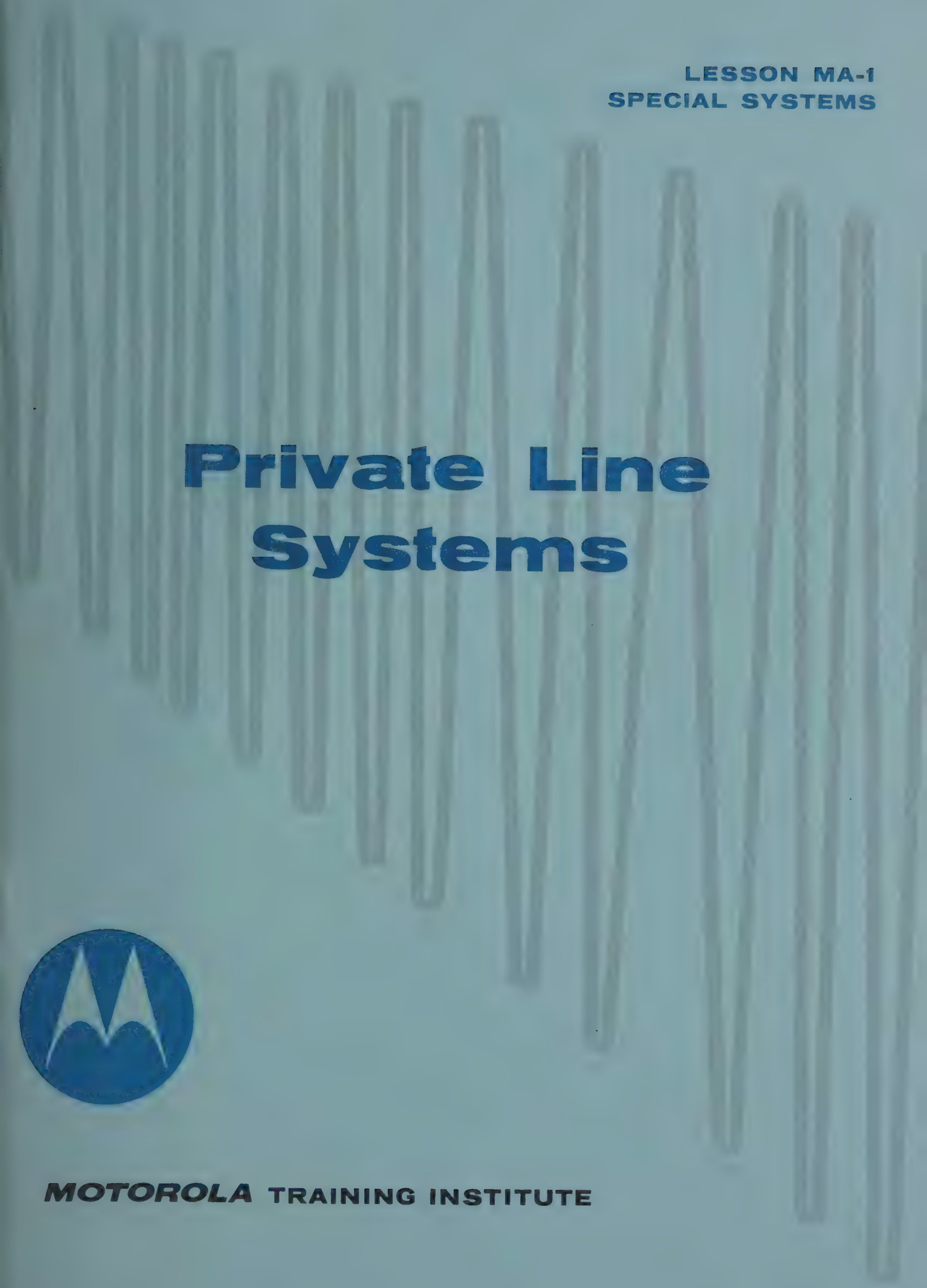
LESSON MA-1
SPECIAL SYSTEMS



Private Line Systems

MOTOROLA TRAINING INSTITUTE

A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON MA-1
SPECIAL SYSTEMS

Private Line Systems

—one of a series of lessons on two-way FM communications—

MOTOROLA TRAINING INSTITUTE
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PREFACE

This is one lesson of a complete Motorola Home-Study Course which presents to the Service Technician both the principles of operation and the maintenance of two-way FM radio systems. The program covers mobile, portable and base station equipment, including the latest transistorized units.

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TWO-WAY COMMUNICATIONS

PRIVATE LINE SYSTEMS

LESSON MA-1

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DISABLING THE PRIVATE LINE SQUELCH .... Page 13

DUAL SQUELCH .... Page 14

NOTICE

Diagrams and figures referenced in text are "fold-outs" in back of each lesson, for use while studying. The Examinations are also there.

Like service organizations in other fields, those involved in the maintenance of two-way radio also realize the many advantages of having two-way radio.

TWO-WAY COMMUNICATIONS
PRIVATE LINE SYSTEMS

Lesson MA-1

Introduction

We have previously referred to the crowded conditions associated with two-way mobile communications, and we pointed out that this congestion has been growing continuously, so that many services are today compelled to share the same channel. Several taxicab companies for example, may find themselves required to use the same channel, if they wish to have two-way communications.

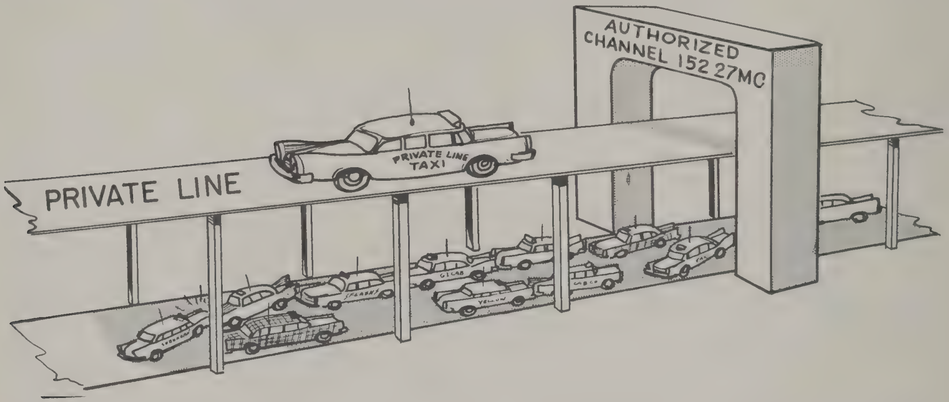
Under these conditions, with the usual carrier-operated squelch, the mobile operator must listen to all messages on the channel, although only a small percentage of them may be directed to him. This is very bothersome.

One solution to this problem is to use Motorola ''PRIVATE LINE'' radio equipment. With this equipment, the only time any sound reaches the loud-speaker is when the carrier belongs to one of the stations within the system. The speakers are silenced at other times. As soon as a ''system'' transmitter comes on the air, however, the receiver squelch is opened and the receiver is subject to the same operating conditions as any other receiver.

Private Line radio operation is achieved by means of a unique squelch system which silences the audio section of the receiver. The squelch is not operated by the carrier and noise reduction, as is usually the case, but by a low-frequency audio tone which constantly modulates the carrier. This audio tone is below the voice range of 300-3000 cps, however, and special filters are used to eliminate it in the audio stages of the receiver. By means of highly selective circuits and a high-Q vibrating reed, the squelch is made insensitive to all audio frequencies except that one to which it is tuned. Ten audio frequencies (between 100 and 136.5 cps) are available for this purpose. Another reed is incorporated in the transmitter, and its frequency must be the same as that of the reed in the receiver. It is thus possible to have as many as ten different systems on the same channel and still maintain ''Private Line'' radio operation for each system.

Advantages of Private Line Operation

The main advantage of Private Line radio operation, as we have



Although Private Line Radio is on the Same Channel and in the Vicinity of Other Systems, it Effectively Provides a New and Nuisance-Free Channel.

just seen, is that the operator is freed from the necessity of listening to all the messages of other systems operating on the same channel.

Another advantage of Private Line radio systems is that the equipment is continuously operated at full squelch sensitivity. With the conventional squelch system the sensitivity of a receiver squelch is subject to the setting of the squelch control. With the correct setting of this control, a weak signal will open the squelch. If the squelch control is advanced too far, however, the squelch sensitivity is lowered and this same signal may not be strong enough to open the squelch circuit.

The tone-operated squelch permits the sensitivity of the receiver to remain at its full value; the squelch setting is not adjustable. In Private Line radio operations, the squelch will always be open for the weakest signal that is readable.

With his receiver squelched and in the absence of the carrier with its correct squelch tone, the operator is not only relieved from the necessity of listening to other signals on the same channel, he is also oblivious of interference signals, intermodulation and image response. Such "interference" may still be taking place in the receiver circuits, for this portion of the receiver is operating at all times, but the speaker is silenced and the operator does not hear it. As soon as his receiver is activated, by the correct carrier and tone squelch, however, it will operate in a normal manner, being subject to all the interference signals listed above.

Basic Principle of Operation -- Transmitter and Receiver

Figure 1 shows the block diagram of a Private Line transmitter which is designed to operate in the high band (144-174 mc). The same system is also used for low-band (25-54 mc) and 450-mc equipment.

The transmitter block diagram is the same as that previously studied with the exception of the tone oscillator (TK 349), which generates a low frequency audio tone, somewhere between 100 and 136.5 cps. The exact frequency is determined by the reed installed. Motorola uses the term "VIBRASENDER" to identify this particular oscillator reed.

The tone oscillator output is applied to the phase modulator together with the audio modulation. Hence, the coding tone will be present at the transmitter output as long as the equipment is on the air.

Figure 2 shows the block diagram of a Private Line receiver. To be consistent with the transmitter of figure 1, the diagram is that of a high-band receiver. The entire front-end, low-frequency IF, limiter and discriminator sections of the receiver are the same as for any conventional receiver. The point of difference in this Private Line receiver, however, is to be found in the squelch circuitry. The discriminator output contains the audio message which is to be reproduced; it also contains the Private Line tone signal. This output is applied both to the low-pass amplifier and to the audio amplifier. Filters in the low-pass amplifier reject the higher audio signals, passing only those frequencies below 300 cps. The coding tone thus reaches the limiter amplifier where it is further amplified. The amplification is sufficient to properly drive the resonant reed, which Motorola calls the "VIBRASPONDER."

When the correct tone is received, the reed is energized, closing contacts so as to apply the negative DC bias voltage from the limiter to the grid of the DC amplifier stage. This negative voltage disables the squelch, allowing the receiver audio section to operate normally. When the correct tone is not present to operate the vibrasponder, the negative voltage from the limiter does not reach the DC amplifier, the squelch is closed, and the receiver is silent. Thus, the only time that the receiver audio section is operative is when a tone of the proper frequency is received.

The highest frequency used for the audio tone (136.5 cps) is considerably lower than the audio voice range used in two-way communications (300-3000 cps). It is therefore improbable that any normal voice transmission will open the squelch of the Private Line receiver.

Transmitter Circuit Analysis

Figure 3 shows the complete schematic of the tone oscillator used in a typical Private Line transmitter. The output of this oscillator is applied to the modulator so that the RF carrier will be modulated by the coded audio tone signal whenever the transmitter is on the air, and this signal operates the squelch in the receiver. A triode-pentode tube (V201) is used as a resistance coupled type of oscillator, with the Motorola Vibrasender resonant reed controlling the frequency. This reed is a very high-Q device and it has a frequency stability of .15% over a temperature range of -20° to $+80^\circ$C. Because of its high Q, it is a relatively slow starting device and it would interpose a time delay if it were operated during transmission periods only. Instead, the B supply is present at all times and the tone oscillator is kept in constant operation. With this arrangement, the tone modulates the signal as soon as the transmitter is operated.

Only Those Channel Signals Which Contain the Proper Code Tone are Heard in the Private Line Receiver.

The output of V201A is coupled to the grid of V201B. The plate circuit of V201B is fed back to the grid of V201A, through R202 and C201. The operation of this circuit is similar to that of a multivibrator.[1] The vibrasender reed acts as a frequency controlling device in the grid circuit of V201A. The coil energizes the reed, which vibrates at its natural frequency. The vibrating reed induces a voltage in the coil which is connected between grid and ground, and the operating frequency of the oscillator is thus controlled.

Automatic gain control, for a constant output voltage, is obtained from the grid of V201B. The grid-leak voltage developed across R209 is fed to the grid of V201A, limiting the gain and output of the oscillator. Capacitor C206 between the two plates prevents the circuit from oscillating at higher frequencies. The negative feedback resulting from C206 helps produce a nearly sinusoidal output waveform. There is also a low-pass filter (R207, C205) in the output line to the modulator, and this filter has an attenuation characteristic of 6 db per octave.

The two cathodes are connected to ground only when the vibrasender assembly is plugged into its socket. This prevents the oscillator from operating at some random frequency if the vibrasender should be removed. In order to change from one control or coding frequency to another, all that is required is to replace the reed assembly with one having the desired frequency.

If the carrier deviation due to the coding signal should become too great, the higher voltage in the receiver audio circuits will cause

---

1. See TM 11-672, pages 59-84.

a hum at a harmonic of the frequency of the coding signal. Insufficient deviation, however, may not produce sufficient voltage to operate the Vibrasponder. Optimum operation is obtained when the deviation is between 1 and 2 kc, and the tone oscillator is designed for an output voltage sufficient to produce this deviation. There is no output adjustment by which the serviceman can control the output voltage, but it is held nearly constant by the AGC action already described.

The Private Line receiver circuitry in figure 4 corresponds to the block diagram of the receiver, shown in figure 2. This is only a partial diagram, but the remaining part is the same as any conventional receiver.

The audio input from the discriminator (upper right) goes both to the audio amplifier, V112B, and to the low-pass amplifier, V112A. By means of C153, C155 and C156 between the input and V113A, the voice frequencies are attenuated, only the coding frequencies reaching the vibrasponder driver stage (V113A) with any magnitude. The vibrasponder amplifier is in reality a limiting amplifier, operating at the saturation level for normal coding signals. Thus the drive (for the vibrasponder in the plate circuit) is controlled and remains constant for all normal operating conditions of the equipment. The high Q of the Vibrasponder prevents it from operating for any coding signal other than that of the natural vibrating frequency of the reed. When a signal having the correct frequency is applied, the reed vibrates vigorously, closing the contacts, B-B. This is an intermittent contact, but the filtering network (R148, R147 and C159) applies a nearly constant DC to the grid of the DC amplifier control tube (V113B). This negative voltage comes from the grid of the first limiter stage (not shown in figure 4).

The negative bias at the grid of the DC amplifier is sufficient to prevent that tube from conducting. The squelch is thereby opened and the audio stage may now operate normally. Basically the action is as follows:

The grid of the audio amplifier V112B is at the same DC potential as the plate of the DC control tube 113B. (This is effected by the DC path from the plate to the grid, through the tone filter). When V113B is conducting, its plate potential is low. This leaves the grid of V112B negative with respect to its cathode and cuts off the plate current in this tube. When the grid of V113B is made negative, this tube no longer conducts and its plate potential rises, making the grid of V112B less negative with respect to its cathode. The audio stage (V112B) may now operate normally.

In order to prevent a tone hum in the speaker, it is necessary to prevent the coding tone from reaching the plate circuit of the audio amplifier, V112B. Considerable attenuation of the lower frequencies is provided between the discriminator and the amplifier input, and the tone filter offers negative feedback between the plate and grid of the amplifier. As a result of this arrangement, the over-all amplification of the stage is very low for the frequencies within the coding frequency range, but normal amplification is provided for the voice frequencies. From V112B, the audio is applied to the power amplifier and thence to the speaker.

The cathode of the output stage is grounded in the normal manner for mobile installations but further provision must be made for reduction of hum which may be remaining in the output of the base station receiver. (This hum is too low to be noticed in mobile equipment, but it may be heard under quiet monitoring conditions such as encountered in base station operation.) This is accomplished by making the cathode circuit degenerative at the low audio frequencies -- those below the voice range. To perform this task, a filter having a high impedance at the low frequencies is inserted between cathode and ground to obtain inverse feedback. The output stage thus provides very little amplification for voltages present at the coding frequency range, but operates in the normal manner for voice frequencies.

The Private Line receiver may be operated as Private Line radio equipment by grounding the cathode of the DC control tube. This is facilitated by a switch which is mounted on the control-head (not shown in figure 4). If the cathode is opened at the switch, the squelch circuit is disabled and it cannot quiet the receiver. With his speaker on constantly, the operator may monitor all signals within the channel, or as a quick check of his receiver's operation. When no carrier is present, there is no squelch to provide receiver silencing, and the characteristic hiss, or FM receiver noise will be heard.

The Private Line radio squelch remains open as long as the correct carrier is being received, because the latter is modulated continuously by the tone oscillator at the transmitter. Other carriers (not having the correct coding signal) will not operate the squelch, and the receiver remains silenced.

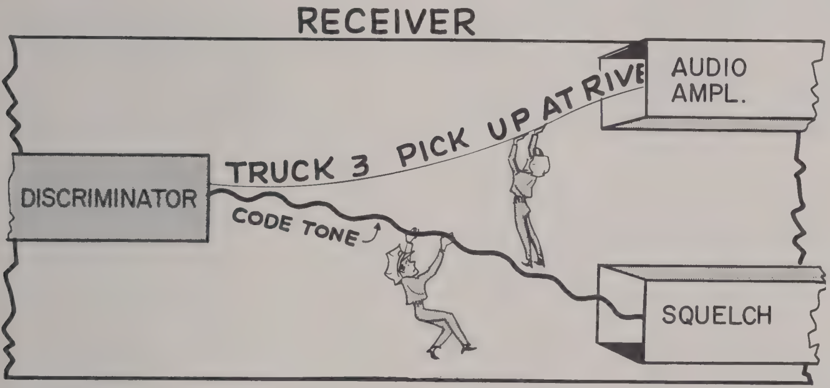
Squelch Tail

When a transmission is completed and there is no longer any carrier present to provide quieting, the squelch might be expected to close, silencing the receiver. It is true that as soon as the squelch circuit goes into operation the receiver is silenced, but in actual practice the time constants of the squelch circuitry will keep the audio section of the receiver open for a short period of time after the carrier is removed. In the absence of a carrier to provide quieting and with the squelch still open, the typical FM noise reaches the speaker. This short burst of noise which is heard in the speaker as the carrier is removed is known as "squelch tail" and it is a common characteristic of communications receivers which are equipped with carrier operated squelch circuits.

Squelch tail can be a real source of annoyance in Private Line receivers, where the vibrating reed of the Vibrasponder due to its high "Q" tends to keep the squelch open for a still longer period of time. Special circuitry incorporated in Motorola Private Line radio equipment eliminates this squelch tail.

Squelch Tail Elimination

One simple way to eliminate squelch tail in Private Line radio is to remove the tone modulation at the transmitter a short time before the carrier is discontinued. During the period that the squelch requires to close, the carrier is present to provide quieting. By the time the carrier goes off the air, the receiver is already silenced by the squelch. Squelch tail is thus eliminated by controlling the transmitted signal rather than by any circuitry within the receiver. The operation can be seen by studying figure 5.



Inside the Receiver the Code Tone is Separated from the Message and Applied to the Squelch Circuit. The Correct Code Tone Causes the Squelch to Open, and the Message Reaches the Speaker.

Figure 5 shows the control circuits of the entire equipment, with the control relays in the transmit position. The two squelch-tail controlling relays (K2 and K3) on the squelch-tail eliminator chassis (which is located on the power supply chassis) are energized whenever a ground is supplied at the "B" contact of K3. This connection is made at terminal 16 of TB2. The line may be grounded (1) by the push-to-talk switch on the microphone, or (2) by energizing the transmit-receive relay (K1) on the remote control chassis. Grounding this line completes the path through both relay coils and through the time delay network to a source of continuous B+ voltage (the receiver plate supply). With both relays now energized, they perform the following functions:

The Many Nuisance Messages of Other Systems on the Same Channel are Not Heard in the Private Line Receiver.

Contacts 3 and 4 of relay K3 open, ungrounding the output from the tone oscillator. (While the tone oscillator, which is located on the transmitter chassis, is in continuous operation, its output is grounded whenever relay K3 is de-energized and the tone cannot reach the phase modulator of the transmitter.) With K3 now energized, the tone oscillator output is present at the phase modulator. Relay K2 is also energized, grounding contact 1 through contact 2. This energizes the transmit-receive relay, K1 placing the transmitter in operation. The transmitter is now "on the air" and ready for voice modulation. The carrier is continually modulated with the coding tone, and the receiver squelch has been opened by this tone. We are now ready to see what happens when the operator releases his push-to-talk switch.

As soon as the operator is through with his message he releases the talk switch, breaking the ground connection to relays K2 and K3. Relay K3 releases immediately and the tone output from the tone oscillator is grounded. With the coding tone no longer present at the receiver, the squelch starts to close. This is not an instantaneous action as we have already explained, but there is no squelch tail heard at the receiver, because the carrier is still being received.

Although relay K2 is in series with K3, it does not release at the same time. During the time that K1 of the Remote Control chassis was energized, capacitor C2 was charged, to the voltage across K2. It now starts to discharge through the time-delay network and through the coil of relay K2. The time constant of this circuit will cause relay K2 to stay energized longer than K3. The time delay network will, when adjusted for the proper delay time, hold the relay closed until the squelch in the receiver has had time to operate.

Relay K2 now opens and the ground is removed from the coil of K1. This relay (K1) now releases and shuts off the transmitter (removes the carrier). By this time, however, the receiver squelch has closed and no noise (squelch tail) is heard in the speaker.

Before leaving figure 5 there are several other circuits shown on this schematic which warrant inspection, since they affect the squelch-tail operation of the equipment. When relay K2 releases, contacts 3 and 4 are closed, placing capacitor C2 in parallel with one of the 33K resistors. These resistors are connected as a voltage divider across the receiver B+ supply and a constant voltage is applied to them. The capacitor is thus charged at the time it is placed across the coil of K2. Whenever the operator momentarily presses his push-to-talk switch, and releases it, the capacitor will hold K2 closed, preventing a squelch tail at the receiver. Without such an arrangement, this quick on-and-off action might fail to provide the necessary charge for the capacitor and relay K2 (and K1) would make and break immediately, resulting in a squelch tail at the speaker.

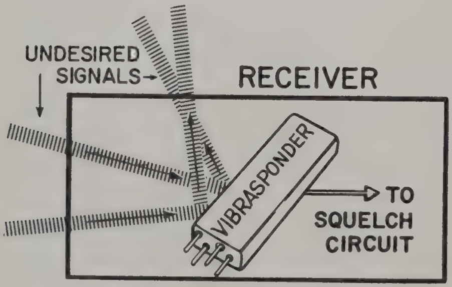
The "Tone oscillator B+ stabilizing network" compensates for B supply voltage changes which occur when the equipment is switched from receive to transmit, and vice versa. During transmission periods, the load on the receiver power supply is greatly reduced and the voltage supply to the tone oscillator increases. However, with contacts 4 and 5 of relay K1 open, a voltage drop is provided by the 6.8K resistor in the supply line to the tone oscillator; this voltage drop is further increased by the 56K resistor which is placed parallel to the line. During receiving periods, the B supply voltage decreases, but the voltage at the tone oscillator remains nearly constant. When it releases, the relay "makes" contacts 4 and 5, placing the two resistors in parallel with each other and in series with the tone oscillator supply line. This means less resistance and less voltage drop across the resistors, which in turn means a steady voltage applied to the oscillator, and the operation is stabilized. Any sharp change in supply voltage would produce undesirable transients in the tone oscillator and impair operation of the equipment.

The squelch tail eliminator shown in figure 5 still has one significant shortcoming--it takes too long for the transmit-receive relay to place the receiver back in operation after the operator has released the "talk" button. Let us suppose that the operator of station number 1 has been talking to station 2. As soon as the message is completed, the operator at station 2 pushes his talk button. The equipment, however, due to the delay circuitry, has not yet returned to the receive position, and operator No. 1 does not hear the beginning of the other operator's reply. It thus becomes desirable to shorten the time it takes a station to return to receive operation, at the same time providing positive squelch-tail elimination at the receiver. This "fast acting" feature is accomplished by means of the circuitry shown in figure 6.

Fast-Acting Squelch Tail Eliminator

The Motorola squelch-tail eliminator shown in figure 6 is fast acting, allowing almost instantaneous call-back from one station to another.

This arrangement provides quick squelch action at the receiver, which allows a quicker release of the transmit-receive relay at the transmitter. By bringing the Vibrasponder to a quick stop, the receiver squelch circuit will close in a shorter period of time. To accomplish this, a tone signal of the same frequency but of an opposing phase is sent out on the carrier and this signal tends to make the reed vibrate in the opposite direction, thereby damping its action. When the reed is sufficiently damped to prevent its contacts from completing the circuit, the carrier can be removed at the transmitter.



At the Private Line Receiver, Undesired Signals Cannot Operate the Vibrasponder and Cause the Squelch to Open.

The transmitter in figure 6 is turned on whenever squelch-tail relay K2 is energized. Relay K2 has two sets of contacts (both sets shown in the released or receive position in figure 6). When K2 is energized (1) one set of contacts (4 and 5) closes the circuit to the slow-release relay K3, which in turn energizes the transmit relay K1; (2) the other set of contacts switches the tone oscillator line from the pentode section to the triode section. The transmitter is now operating, with the tone modulation taken from the triode section of the tone oscillator.

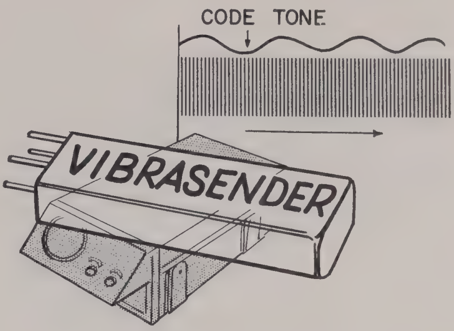
When the operator releases his push-to-talk button, squelch-tail eliminator relay K2 opens. The circuit through the coil of the slow-release relay, K3, is also opened, but the relay contacts remain closed for 120 milliseconds, during which time the transmitter remains on the air.

With the release of relay K2, the tone modulation of the carrier was switched from the triode section of the oscillator to the pentode section by the second pair of K2 contacts. The opposite phase of the tone signal from the pentode section now opposes the vibration of the reed in the vibrasponder circuit of the receiver, causing a sharp damping of its movement. The reed contacts no longer complete the vibrasponder circuit and the receiver squelch closes. By this time the slow release K3 has dropped out, releasing the transmit-receive relay and switching the system to receive. This phase change of the tone modulation quickly damps the vibrasponder reed in the receiver, thus making it possible to use a short delay time when releasing the transmit-receive relay.

In the Private Line receiver circuit of figure 4, high noise levels could cause the squelch to open under adverse conditions. A slightly different arrangement, figure 7, is possible in the driving circuit for the vibrasponder; two coupling circuits have been provided from the discriminator to the low-pass amplifier.

The coupling circuit through R1 and C1 allows the lower audio frequencies to pass, but provides high attenuation to the upper voice and higher frequencies. The more direct capacitance coupling (C2) to the grid of the amplifier introduces a certain amount of high-frequency noise energy, present at the discriminator output without a signal. Both the low-frequency noise energy and the high-frequency signal are amplified in this stage, both reaching the input of the following stage, a cathode-follower type of vibrasponder driver.

This stage is a clipper-limiter, and nearly all input signals drive the stage to plate current cutoff and saturation. Thus there is a maximum amount of signal (noise) power in the output at all times, and this does not vary. With both high and low frequency noise applied, the output is divided between the high and low frequency noise. There is not enough low-frequency energy to fully drive the reed and open the squelch.



The Vibrasender Insures that the Correct Coding Tone Modulates the Transmitter and Reaches the Receiver.

As soon as a carrier enters the receiver, however, the noise quieting effect of the IF limiters reduces the high-frequency noise at the discriminator output. The only signal reaching the low-pass amplifier, then, is the tone signal. All the output power of the vibrasponder driver stage is now concentrated at the tone frequency, the reed is energized, and the squelch opens.

There is another feature of this circuit (figure 7) which makes it immune to noise. By placing the vibrasponder coil in parallel with a low impedance, the coil damps the reed and undesirable noise energy cannot open the squelch. Consider for a moment the action if a high impedance instead of a low resistance were in parallel with the coil.

Noise energy reaching the coil sets the reed in motion, only to have successive noise pulses cause damping currents in the coil. The net result? The squelch remains closed. Strong, low-frequency noise pulses, however, occasionally drive the stage to cutoff and, due to the time period of this low-frequency pulse, the stage is held at cutoff for some time.

The reed has already been driven by the strong pulse and is now free to vibrate without interruption; the tube is at cutoff and noise energy at the grid does not reach the cathode. The reed continues to vibrate and opens the squelch. The one damping effect upon the reed is the current through the coil, and this depends upon the Q of the coil. The high resistance in parallel with the coil allows a high Q and there is but little damping.

Now let's see what happens when the vibrasponder coil is in parallel with a low resistance, as in figure 7. Again the strong, low-frequency pulses bias the tube to cutoff and drive the reed. The Q of the circuit now depends on the low resistance of the cathode resistor, and the effective Q is considerably lower.

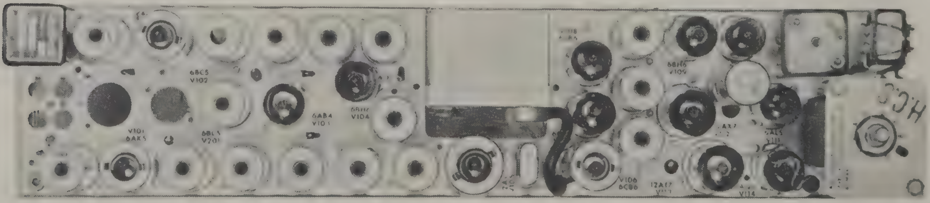
As a result, the coil currents decay quickly and the reed is damped, before the squelch has had time to open.

This arrangement, being relatively free from the triggering effects of noise pulses, will not open the squelch unless the correct tone is applied.

Private Line Systems

Various types of Private Line radio operation will be found in use. One system employs Private Line radio operation only from the control dispatcher at the base station to the mobile units. With this system the mobiles hear only those calls originating at the base; there is no mobile-to-mobile communication so long as the mobile receivers are in Private Line radio position. If the switches at the mobile units are placed in the "Private Line OFF" position, however, the operators can hear all the transmissions on their frequency.

Another type of Private Line radio operation has coding tones



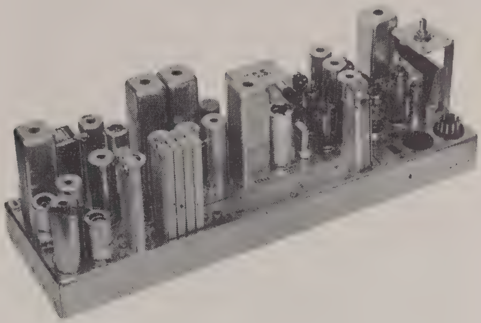
The Vibrasponder is Seen at the Upper Right Corner of this Private Line Receiver.

at all units, giving the entire system freedom from all signals except those of its own net. By means of a switch, any operator may disable his squelch and listen to all messages on the channel. There is no squelch system to silence the receiver between messages, however, and there is considerable FM noise in the speaker.

Squelch-tail elimination may or may not be used; it depends upon the particular needs of each system. The squelch-tail eliminator circuit is often incorporated in the base transmitter only, so that the mobile receivers do not hear the squelch-tail noise. Without the squelch-tail eliminator included in the mobile transmitters, the base receiver is subject to squelch tail.

Disabling The Private Line Squelch

Let us return briefly to figure 5, which shows a Private Line base station designed to operate on the 450-mc band. It is sometimes desirable for the operator to disable his squelch circuit to monitor the band or to check on the operation of his receiver. This operation can be performed by closing a switch on the remote console. The resulting current in the control line produces a voltage drop across relay K1 (shown in the remote control chassis). This current is not sufficient to operate the relay, but the voltage drop across the relay coil, when applied to the cathode of the squelch control tube in the receiver, stops that tube from conducting and, in turn, opens the squelch.

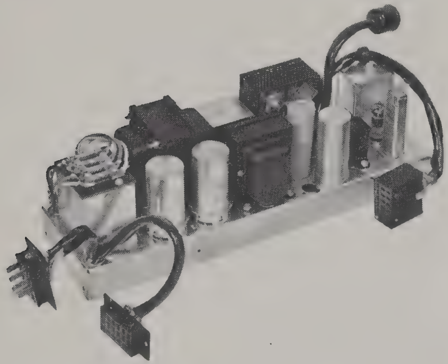


The Vibrasponder is Seen at the Right Front Section of this 450-MC Receiver.

This circuit enables the operator to disable the receiver squelch from his remote control console. The Private Line radio disabling system of figure 5 has one side of the control line grounded. This unbalance in the line can be a source of hum. An alternate circuit for disabling the base station Private Line squelch is shown (the dotted lines) immediately below the remote control chassis.

A second relay (K4) is connected in series with control relay K1. (Jumper JU3 is removed.) In parallel with K4, we find a diode rectifier. This rectifier acts like a bypass to K4 for the DC current (approximately 10 ma) which operates K1.

When the operator at the remote console closes his Private Line switch, a DC current is again established in the control line, but it is in the opposite direction. This current, only 4 ma, cannot operate relay K1; it must pass through the coil of relay K4, however, for the crystal offers a high impedance to current in this direction. The relay now closes, and disables the squelch control tube by opening its cathode circuit.



The Vibrasender and Oscillator, Which Controls the Tone Modulation of the Transmitter, is Usually Located on the Power Supply Chassis.

The ground can be removed from one side of the control line in this alternate circuit, and the line may now be balanced for minimum hum pickup. The operator may then monitor the channel for a period of time, but in the absence of transmissions or signals from other transmitters, the receiver becomes very noisy. It is evident that a system incorporating both Private Line radio squelch and normal squelch (carrier squelch) would be desirable. This combination is used in the Motorola "dual squelch" Private Line system.

Dual Squelch

The simplified circuit of figure 8 shows the squelch section of a Private Line receiver which incorporates both a tone-operated squelch and a carrier-operated squelch. A switch on the operator's control head enables selection of either private line squelch operation or normal squelch operation. With the switch in the PRIVATE LINE position, the carrier squelch section is disabled; the only operative squelch circuit now is the Private Line tone circuit, and only these signals having the proper coding tone will be heard. With the switch in the off position, however, all transmissions on the channel will be heard; the carrier-operated squelch, now active, silences the receiver between transmissions.

The operation of the circuit with the operator's switch in the PRIVATE LINE position is the same as if the carrier circuitry were not included. The cathode of the Private Line DC amplifier is grounded, making the Private Line squelch independent of the carrier squelch section. The Private Line DC amplifier tube will be conductive or nonconductive, depending upon the bias on its grid. This, in turn, is determined by the activity of the vibrasponder reed. If the coding tone is not applied, the reed does not vibrate and, because there is no large negative bias applied to the grid, the DC control tube conducts, thereby squelching the receiver.

When the correct tone is received, the reed vibrates and applies the -17 volt bias from the limiter grid to the grid circuit of the control tube. This biases the control tube beyond cutoff, making it nonconductive and opening the squelch.

When the PRIVATE LINE switch is placed in the "off" position, the Private Line DC amplifier and the carrier squelch DC amplifier are placed in series as far as their plate currents are concerned. If either of these tubes should now become nonconductive the receiver squelch will open.

The operation of the carrier squelch section is the same as that of the noise-compensated squelch circuit previously explained. Noise from the discriminator, in the absence of a carrier, is applied to the noise amplifier. The amplifier output is then rectified by the noise rectifier and this positive DC voltage is applied to the grid of the DC control tube. This positive voltage opposes the negative voltage from the grid of the limiter, and the bias on the DC amplifier stage approaches zero, allowing the DC amplifier tube to conduct. The Private Line DC amplifier of figure 8 is also conductive in the absence of the Private Line tone and the audio tube is biased beyond cutoff. The receiver is squelched.

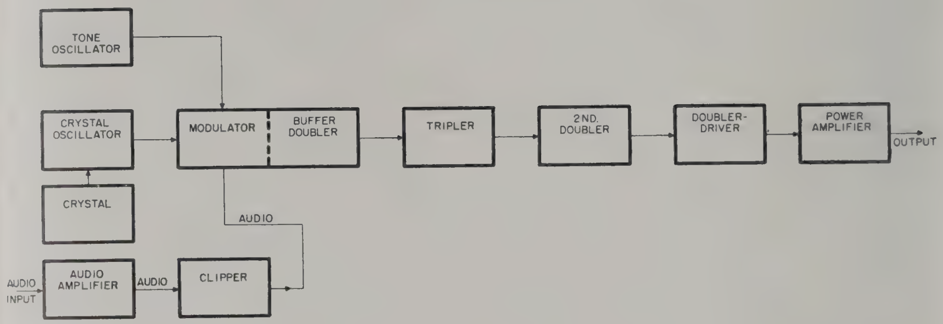
As soon as a carrier is received, the action of the limiters reduces the noise input to the noise amplifier and the positive output voltage from the noise rectifier is also greatly reduced, perhaps to zero. As a result, the limiter grid voltage makes the grid of the carrier squelch DC amplifier, highly negative and the tube is at cutoff. With the carrier DC amplifier at cutoff there can be no current through the private line DC amplifier, and the squelch is open. Any signals coming into the receiver will now be heard. So long as the carrier is being received, the carrier squelch DC amplifier is at cutoff and keeps the squelch open.

The operator of dual-squelch equipment may listen either (1) to signals of his own system, or (2) to any signals on the channel. (This is made possible by the PRIVATE LINE switch.) In either instance, one of the squelch circuits is effective, silencing the receiver between transmissions.

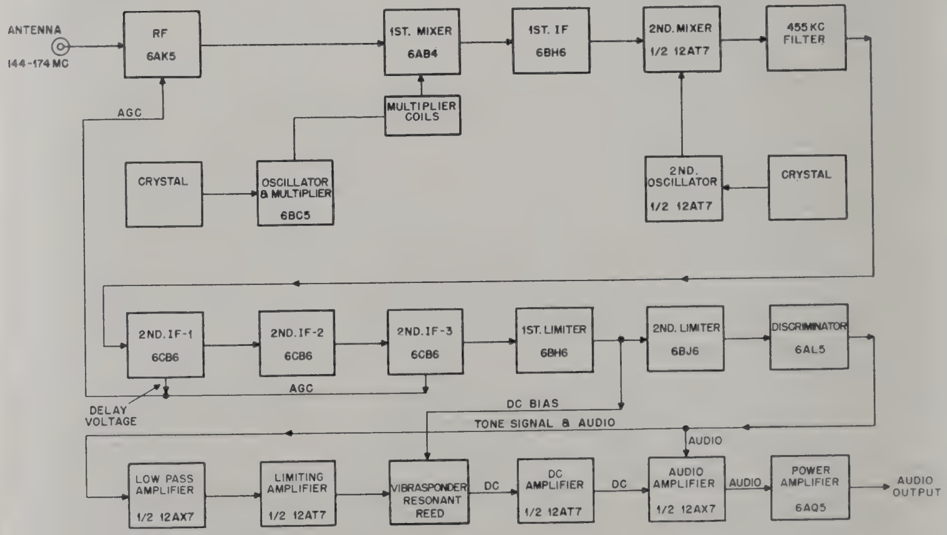
STUDENT NOTES

STUDENT NOTES

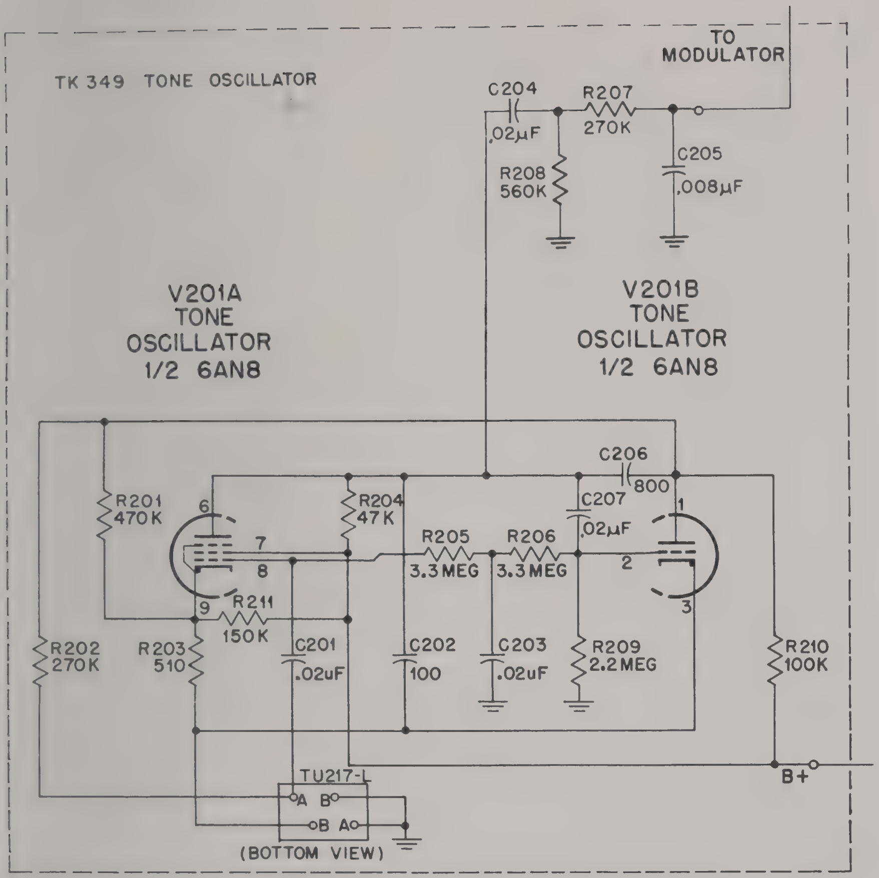
STUDENT NOTES



HIGH-BAND "PRIVATE LINE" TRANSMITTER
FIGURE 1



HIGH-BAND "PRIVATE LINE" RECEIVER
FIGURE 2


TK 349 TONE OSCILLATOR
TO MODULATOR
C204
.02μF
R207
270K
R208
560K
C205
.008μF
V201A
TONE
OSCILLATOR
1/2 6AN8
V201B
TONE
OSCILLATOR
1/2 6AN8
C206
800
R201
470K
R204
47K
C207
.02μF
6
7
8
9
1
2
3
R205
3.3MEG
R206
3.3MEG
R211
150K
R202
270K
R203
510
C201
.02uF
C202
100
C203
.02uF
R209
2.2MEG
R210
100K
B+
TU217-L
A
B
B
A
(BOTTOM VIEW)

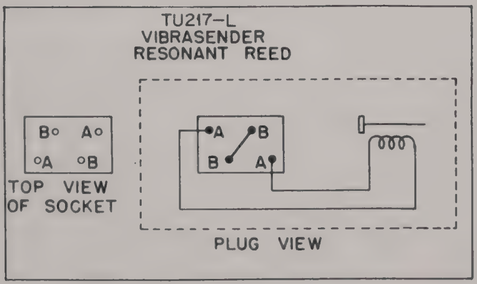

TU217-L
VIBRASENDER
RESONANT REED
B
A
A
B
TOP VIEW
OF SOCKET
A
B
B
A
PLUG VIEW

FIGURE 3

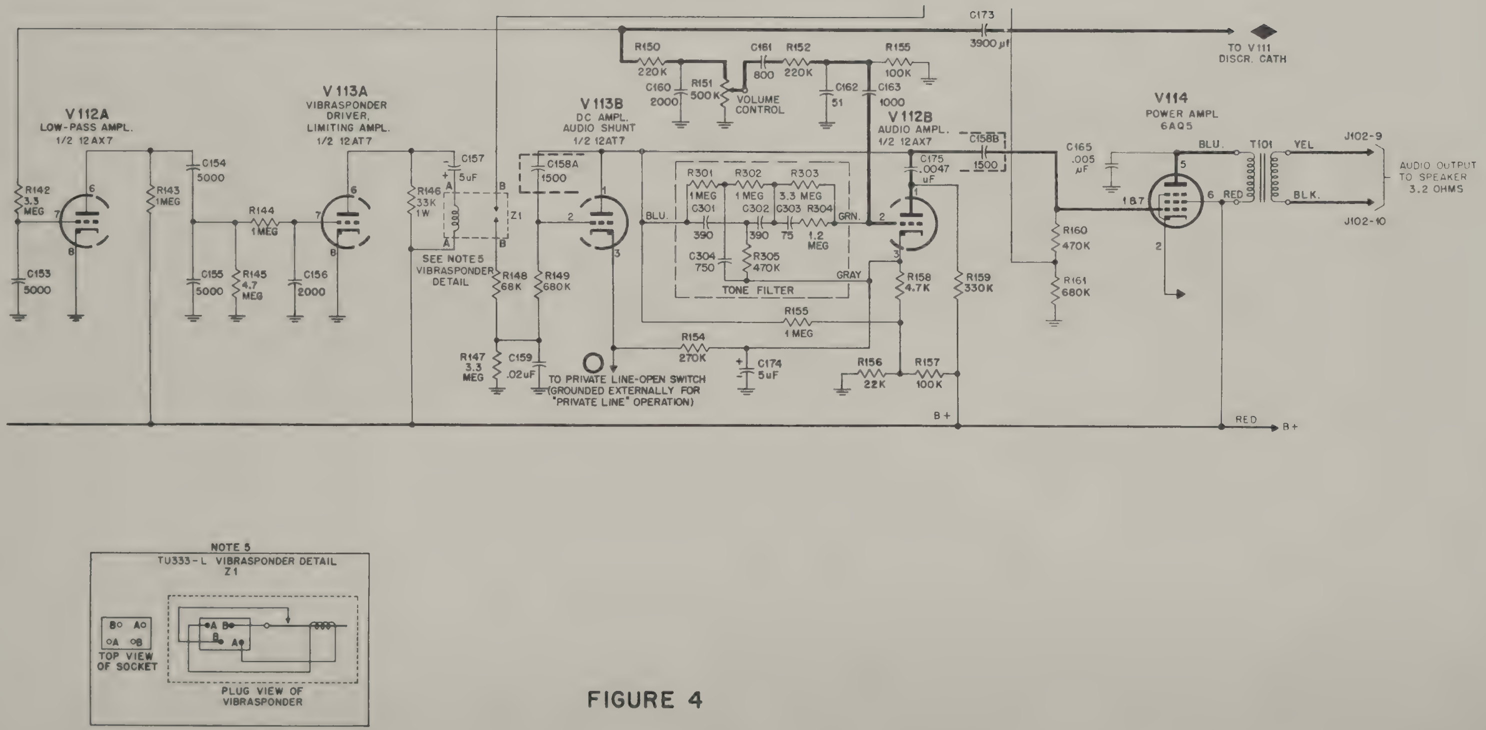

V112A
LOW-PASS AMPL.
1/2 12AX7
R142 3.3 MEG
C153 5000
R143 1MEG
C154 5000
C155 5000
R144 1MEG
R145 4.7 MEG
C156 2000
V113A
VIBRASPONDER DRIVER, LIMITING AMPL.
1/2 12AT7
R146 33K 1W
C157 5uF
Z1
SEE NOTE 5 VIBRASPONDER DETAIL
R148 68K
R147 3.3 MEG
C159 .02uF
R149 680K
C158A 1500
V113B
DC AMPL. AUDIO SHUNT
1/2 12AT7
TO PRIVATE LINE-OPEN SWITCH (GROUNDED EXTERNALLY FOR "PRIVATE LINE" OPERATION)
R150 220K
C160 2000
R151 500K
VOLUME CONTROL
C161 800
R152 220K
C162 51
C163 1000
R155 100K
C173 3900 µf
TO V111 DISCR. CATH
BLU.
R301 1MEG
C301 390
R302 1 MEG
C302 390
R303 3.3 MEG
C303 75
R304 1.2 MEG
C304 750
R305 470K
GRN.
GRAY
TONE FILTER
R155 1 MEG
R154 270K
C174 5uF
R156 22K
R157 100K
V112B
AUDIO AMPL.
1/2 12AX7
C175 .0047 uF
C158B 1500
R158 4.7K
R159 330K
B+
C165 .005 µF
R160 470K
R161 680K
V114
POWER AMPL
6AQ5
BLU.
RED
T101
YEL
BLK.
J102-9
J102-10
AUDIO OUTPUT TO SPEAKER 3.2 OHMS
RED
B+
NOTE 5
TU333-L VIBRASPONDER DETAIL
Z1
TOP VIEW OF SOCKET
PLUG VIEW OF VIBRASPONDER

FIGURE 4

STUDENT NOTES

STUDENT NOTES

CONDITIONS

1. 117 VOLT 60CPS AC LINE CONNECTED TO FUSE BLOCK.
2. CONTROL LINE CONNECTED TO TERMS 7 & 8 BOTTOM ROW REMOTE CONTROL CHASSIS
3. PUSH-TO-TALK BUTTON DEPRESSED (AT REMOTE CONTROL CONSOLE)

RESULTS

1. REMOTE CONTROL CHASSIS TRANSMIT-RECEIVE RELAY ENERGIZED
2. SQUELCH TAIL ELIMINATOR RELAYS ENERGIZED
3. POWER SUPPLY TRANSMIT-RECEIVE RELAY ENERGIZED.
4. RED LIGHT ON CABINET ENERGIZED. (INDOOR MODEL ONLY).
5. HIGH B+ APPLIED TO FINAL RF AMPLIFIER.
6. ANTENNA RELAY ENERGIZED.
7. TONE-MODULATED CARRIER ON AIR.

RELEASE OF PUSH-TO-TALK BUTTON

1. SQUELCH TAIL ELIMINATOR RELAY K3 DE-ENERGIZES, GROUNDING TONE OUTPUT IMMEDIATELY
2. CAPACITOR C2 DISCHARGES THROUGH RELAY K2 AND DELAY ADJUSTMENT NETWORK.
3. K2 REMAINS ENERGIZED FOR THE TIME CONSTANT PERIOD.
4. TRANSMIT-RECEIVE RELAY K1 REMAINS ENERGIZED FOR THE TIME CONSTANT PERIOD.
5. UNMODULATED CARRIER REMAINS ON THE AIR FOR THE TIME CONSTANT PERIOD.

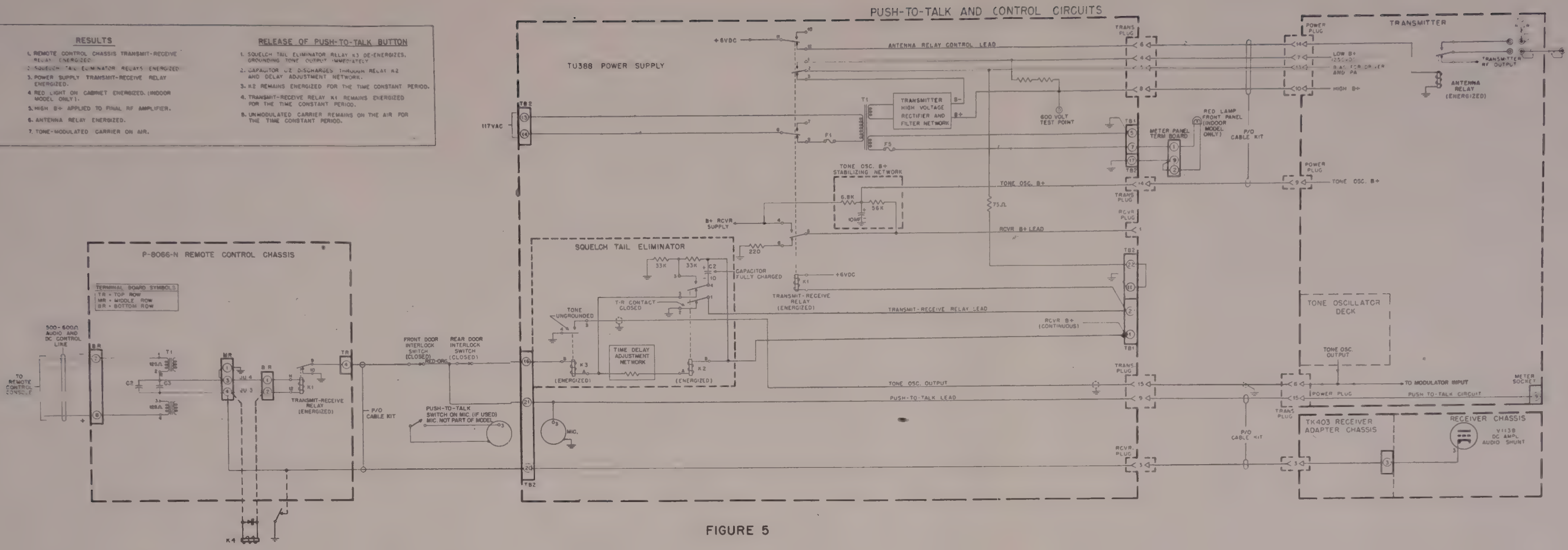


FIGURE 5

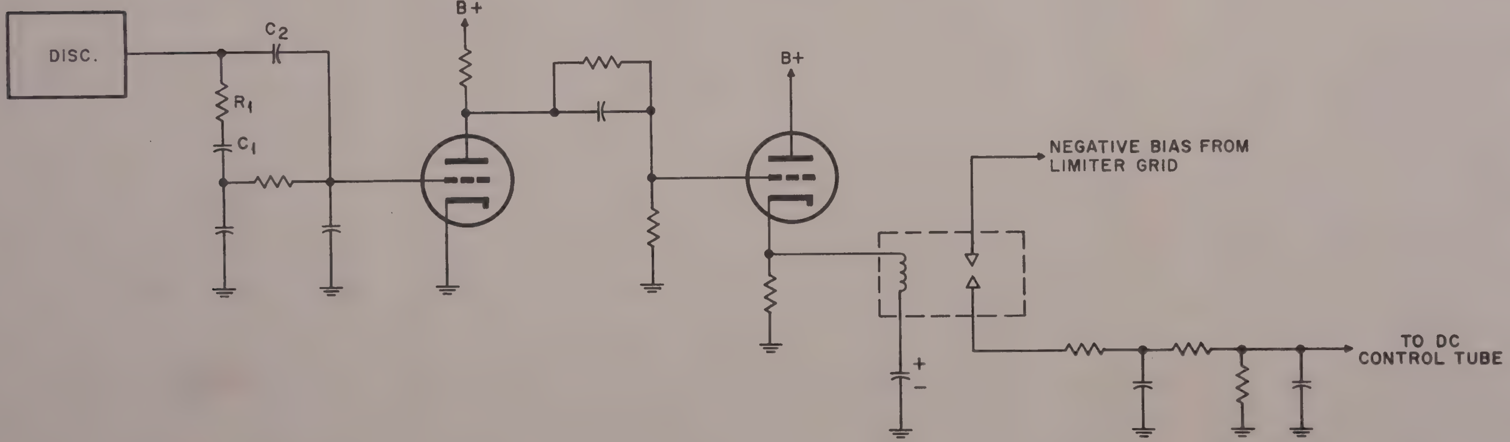
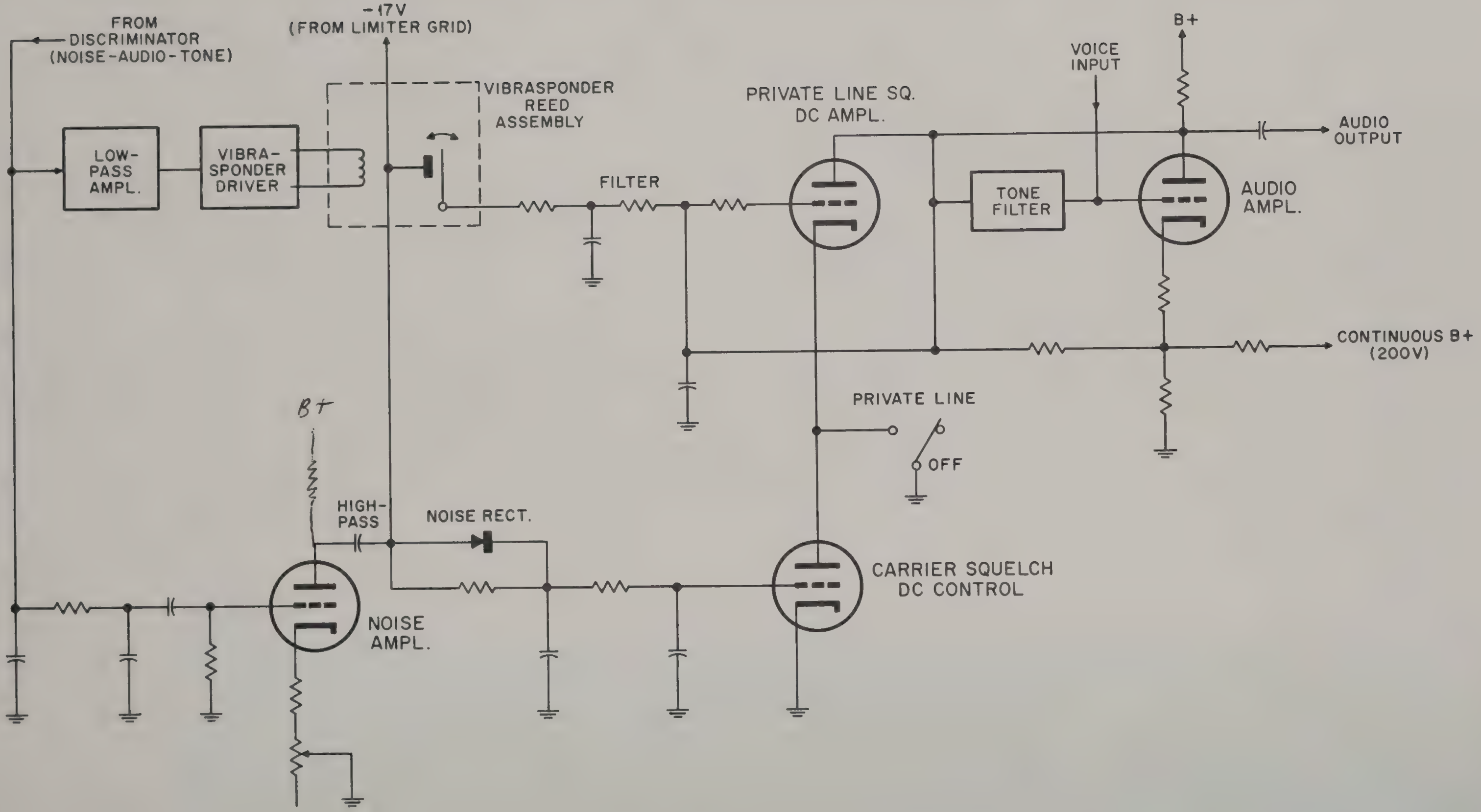


FIGURE 7



DUAL SQUELCH
FIGURE 8

STUDENT NOTES

STUDENT NOTES

STUDENT NOTES

FAST-ACTING SQUELCH CONTROL CIRCUIT DIAGRAM

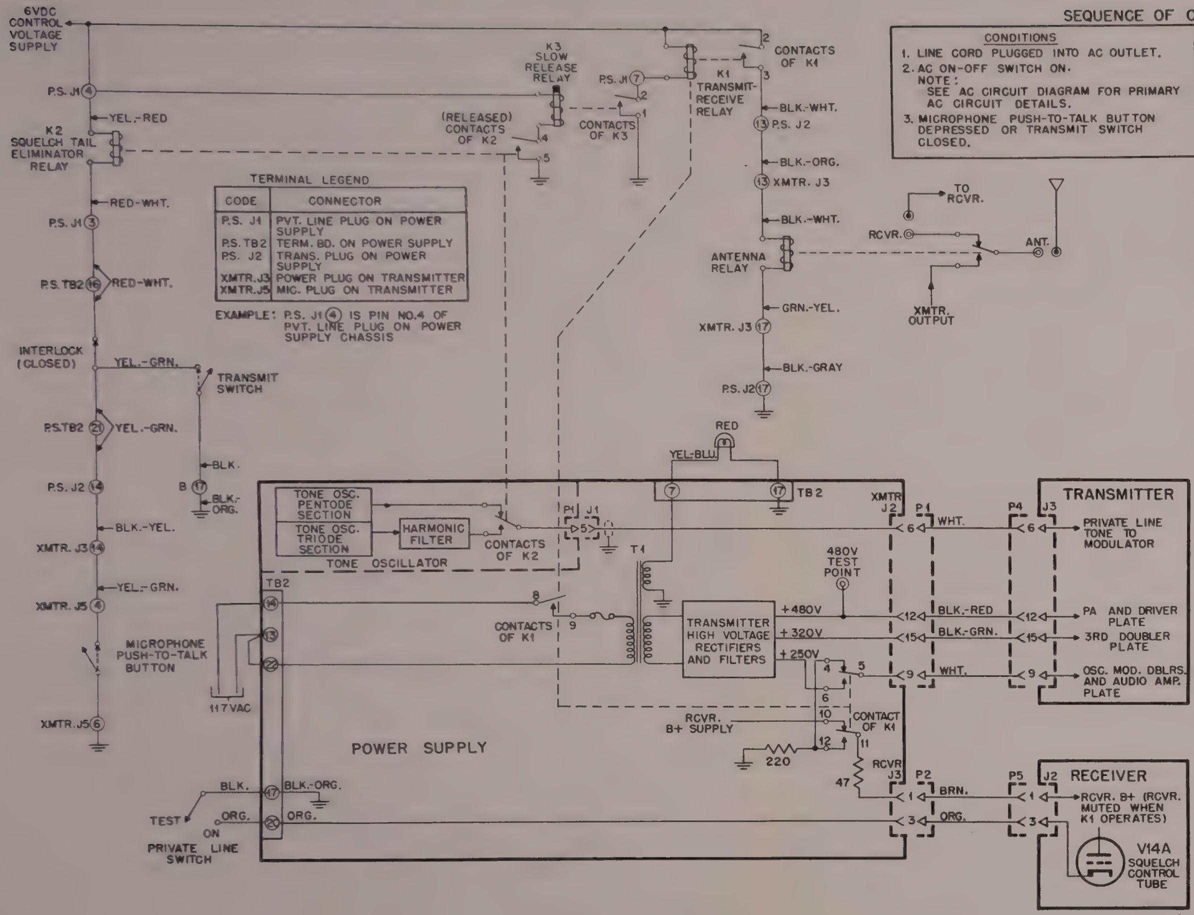


FIGURE 6

TERMINAL LEGEND

CODE	CONNECTOR
P.S. J1	PVT. LINE PLUG ON POWER SUPPLY
P.S. TB2	TERM. BD. ON POWER SUPPLY
P.S. J2	TRANS. PLUG ON POWER SUPPLY
XMTR. J3	POWER PLUG ON TRANSMITTER
XMTR. J5	MIC. PLUG ON TRANSMITTER

EXAMPLE: P.S. J1 ④ IS PIN NO.4 OF PVT. LINE PLUG ON POWER SUPPLY CHASSIS

SEQUENCE OF OPERATIONS

CONDITIONS

1. LINE CORD PLUGGED INTO AC OUTLET.
2. AC ON-OFF SWITCH ON.
   NOTE:
   SEE AC CIRCUIT DIAGRAM FOR PRIMARY AC CIRCUIT DETAILS.
3. MICROPHONE PUSH-TO-TALK BUTTON DEPRESSED OR TRANSMIT SWITCH CLOSED.

RESULTS

1. SQUELCH TAIL ELIMINATOR RELAY K2 IS ENERGIZED.
2. CONTACTS OF K2 OPERATE SLOW RELEASE RELAY K3.
3. CONTACTS OF K3 OPERATE TRANSMIT-RECEIVE RELAY K1.
4. CONTACTS OF K1 OPERATE ANTENNA RELAY.
5. CONTACTS OF K1 APPLY 117VAC TO TRANSMITTER HIGH VOLTAGE POWER SUPPLY.
6. CONTACTS OF K2 CONNECT TRIODE TONE OSCILLATOR OUTPUT TO TRANSMITTER MODULATOR.
7. TONE-MODULATED CARRIER GOES ON THE AIR.
8. RED LIGHT ON FRONT PANEL GOES ON.

RELEASE OF PUSH-TO-TALK BUTTON

1. SQUELCH TAIL ELIMINATOR RELAY K2 CONTACTS OPEN IMMEDIATELY.
2. CONTACTS OF K2 TRANSFER MODULATOR TONE INPUT FROM TRIODE SECTION TO PENTODE SECTION OF TONE OSCILLATOR.
3. PHASE-SHIFTED PENTODE OUTPUT DAMPS VIBRATIONS OF RESONANT REED AT RECEIVER.
4. AFTER 120 MILLISECONDS SLOW RELEASE RELAY BREAKS TRANSMIT-RECEIVE RELAY CIRCUIT, TAKING CARRIER OFF THE AIR.
5. RED LIGHT GOES OUT. ANTENNA RELAY TRANSFERS ANTENNA TO RECEIVER.

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A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON MA-2
SPECIAL SYSTEMS

Selective Signaling Equipment

MOTOROLA TRAINING INSTITUTE

A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON MA-2
SPECIAL SYSTEMS

Selective Signaling Equipment

—one of a series of lessons on two-way FM communications—

MOTOROLA TRAINING INSTITUTE
4501 W. AUGUSTA BLVD., CHICAGO 51, ILLINOIS
APPROVED BY THE STATE OF ILLINOIS
DEPT. OF REGISTRATION AND EDUCATION

PREFACE

This is one lesson of a complete Motorola Home-Study Course which presents to the Service Technician both the principles of operation and the maintenance of two-way FM radio systems. The program covers mobile, portable and base station equipment, including the latest transistorized units.

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SELECTIVE SIGNALING EQUIPMENT

LESSON MA-2

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NOTICE

Diagrams and figures referenced in text are "fold-outs" in back of each lesson, for use while studying. The Examinations are also there.

Providing prompt customer service, be it orange juice or rug cleaning, is essential in this competitive age. Thousands of customer service firms are utilizing two-way mobile radio to increase the speed and efficiency of their operations.

SELECTIVE SIGNALING EQUIPMENT

Lesson MA-2

Introduction

In the preceding lesson we discussed the need for a two-way communications system which would provide a certain degree of "privacy" when a channel is shared with others in the same area. We found a solution in the Private Line tone coding system. In this system, receivers will not respond to signals on the channel frequency unless the signal includes the proper coding tone to keep the receiver squelch open.

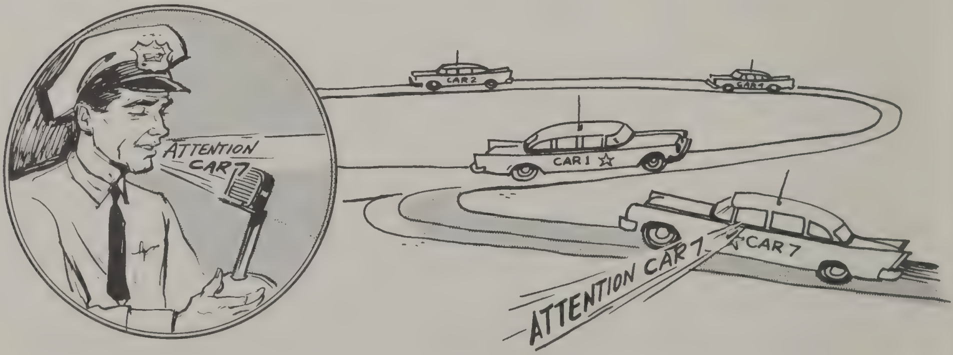
Selective calling equipment insures privacy between stations operating within one system. Motorola's QUIK-CALL system does just that. Either individual stations or combinations of stations may be selected to receive a particular transmission without disturbing other receivers in the same system. This selection is operative only from the base station, not from the mobile units. So long as a receiver is not "called" by the base transmitter, it also will be unresponsive to transmission from other systems using the same channel. This affords a certain degree of "private" operation, for the receiver responds only to those messages meant for it; the operator does not have to listen to a lot of messages which do not concern him.

In operation, the audio circuit is broken before the signals reach the speaker, so that none of the undesired messages will be reproduced. This audio circuit is completed (by the closing of a relay) only when certain coding tones are received. Four tones are used by the QUIK-CALL system, in order to provide a great number of combinations for alerting the different receivers. Since two of the coding tones may be common to several receivers, this arrangement provides considerable flexibility for group calling.

Transmission of the coding tones is automatic. The operator merely selects the tones corresponding to the receiver he wishes to call and then depresses a "code start" button. This activates several relays and timing circuits, which send out the proper alerting tones. The first two tones are transmitted during the first 3/4 second; after a short "silent" interval, the second group of two tones is sent.

All four coding tones will have been transmitted within two seconds from the time the operator depresses the start button. A neon lamp on the control panel tells the operator that the tones are being transmitted. As soon as the coding tones are completed this lamp goes out, which means that the operator may now transmit his message without interfering with the coding signals.

Figure 1A shows a block diagram of the QUIK-CALL equipment used in connection with the transmitter. Twelve tone-oscillators are in constant operation, each oscillator generating a very stable audio signal. For convenience, each tone is identified by a number or letter. In low-frequency tone systems the first 10 tones are identified by the numbers 1 through 0, and the letters A and B designate the two final tones. (High-frequency tone systems have letter designations from C to P, I and O being omitted.)



Quik-Call Radio Provides Selectivity Within a System: One Car may be Called Separately--the Remaining Vehicles in the System are Silent.

The output of the oscillators is fed to the selector box where we find two rows of buttons, the 12 buttons of each row being labeled from 1 through B for low-frequency tones. If the operator wishes to call a receiver having code tones of 1 and 3 for the first tone pulse and tones 5 and 7 for the second code pulse, he depresses buttons 1 and 3 of the first row of buttons and 5 and 7 of the second row. He then pushes the "code start" button momentarily and the signal tones are automatically transmitted. When they are completed, the lamp goes out. The operator may now talk to the operator at the selected receiver.

From the selector, figure 1A, the selected tones are next applied to the timer. The first group of tones selected on the upper row of buttons are transmitted for 0.75 second. (The transmission is controlled by a tube, several relays, and associated circuitry.) After 0.75 second, the transmission of the first group of tones is stopped and there is an interval of about 0.2 second before the second tone pulse starts. This interval is also controlled by a timing circuit. The second group of tones is sent in the next pulse, which also lasts for about 0.75 second. With the completion of this pulse, the QUIK-CALL equipment has performed its assigned function.

Another button at the selector box enables the operator to make a "group call" to several receivers having common code tones. The selection of these tones is made from the lower row of buttons and the operator then depresses the "group-test" button for 4 seconds. All receivers having the tones selected for this group call are thus alerted.

The tones, selected for either QUIK-CALL or group call, pass through an amplifier section before reaching the transmitter. The tone level at the oscillator output is not strong enough to properly modulate the transmitter, so an amplifier becomes necessary. The power supply shown in figure 1A is used both by the tone oscillators and by the amplifier.

At the receiver, the speaker remains disconnected from the output until the proper coding tones have been received. These tones activate a control relay which closes the audio path to the speaker. The block diagram of figure 1B testifies to the simplicity of the system. So long as the operator leaves his microphone (or handset) "on the hook," the receiver will be in QUIK-CALL condition. The relay remains deenergized until the correctly coded signals are received. When this happens the relay connects the receiver output to the speaker. When the operator removes the microphone, however, the speaker is connected directly to the receiver output and the receiver is no longer controlled by the QUIK-CALL circuitry. We shall study this arrangement in detail later.

Pulse Control Circuits

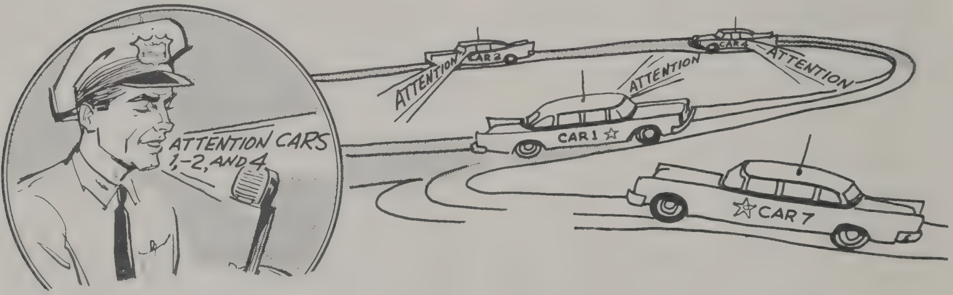
Figure 2 shows the basic method for controlling the transmission of the first group of QUIK-CALL tones. The tones required for the first pulse are selected by depressing the corresponding buttons (switches) in the top row of buttons on the control panel. These tones are transferred to the audio amplifier, but first the contacts of relays K101 and K-1 must be closed. To close relay K101 (located on the selector panel chassis), a sequence of events must take place. First, the "code start" switch is depressed; this charges capacitor C4, which sets the first pulse timer in operation.

As a result, relay K1 (in the cathode circuit of the timer tube V1A) is operated and its contacts are closed. This in turn (1) completes the tone path to the audio amplifier, and (2) completes the path which allows relay K3 to energize.

Relay K3 serves three fundamental purposes in figure 2. First, it turns "on" the transmitter by causing the transmit-receive relay to close. Second, it closes a timing circuit which keeps relay K1 energized for approximately 0.75 second. Third, it closes the path for the operation of relay K101. With relay K1 locked for 0.75 second, relays K3 and K101 will also remain energized during

During This action when K1 is operated, Relay K101 is still in its release position this time. Relay K101 has completed the path for the two tones, which are now applied to the audio amplifier. The tones at the amplifier output are applied to the transmitter modulator.

Relay K1 releases after 0.75 second, but another circuit holds relay K3 until the second tone pulse is started. (This keeps the transmitter on the air.) Relay K1 has released, however, and the tones no longer reach the modulator. Until the second pulse starts, then, there is a short period with no modulation.



An Important Feature of Quik-Call is Group Calling: a Predetermined Group of Vehicles may be Called Simultaneously.

The operation of the second pulse is illustrated in figure 3. Capacitor C2B has charged during the time that relay K1 was operated. When the relay releases, the charged capacitor is connected into the grid circuit of the second timing tube, V1B. The tube conducts and K2 closes, being held closed for approximately 0.75 second by means of a timing circuit. The contacts of relay K2 complete the circuit, keeping K3 closed, and K3 in turn keeps relay K101 energized during the second pulse. The tones selected by the second row of buttons are now transferred to the input of the audio amplifier through the contacts of relays K101 and K2. The transmission of this second pulse lasts for the 0.75 second that relay K2 is held by its timing circuit.

The Console

Figure 4 shows the complete circuit of the QUIK-CALL console. Located near the operator at the base station, this console contains all the components necessary to generate, select, and time the QUIK-CALL signals used in this system.

The console is made up of two basic sections, (1) the selector panel and (2) the power supply and timer chassis. On the selector panel there are two rows of buttons from which the operator selects the various coding signals, a "code start" button which is depressed to start a coding signal, a "group test" button for group calls, a "release" button to release the depressed buttons, an "auto-rel." button which provides automatic release of the buttons after a completed code transmission, an indicator lamp which lights during the transmission of coding signals, and a meter which monitors the level of the tones being sent to the transmitter.

The power supply and timer chassis includes (1) a power supply, (2) a 12-tone oscillator deck (3) the timer circuits, and (4) an audio amplifier section. We shall start our detailed analysis of the QUIK-CALL equipment with the power supply.

The Power Supply

The power supply furnishes four output voltages: 250 VDC, 210 VDC, 8 VDC and 6.3 VAC. These voltages are obtained from two secondary windings. The high-voltage winding has a full-wave bridge selenium rectifier section, with an output of approximately 250 volts (at the filter input). This is used for the high DC supply (designated B++). The low DC supply (210 volts) is provided at the output of the filter section. The 6.3 VAC filament winding is also used to obtain the 8 VDC output. A single rectifier and a filter section produce the positive 8 volts, which is used as a biasing voltage at the cathodes of the tubes in the timing circuits.

Tone Oscillator Deck

Only one tone oscillator is shown in figure 4; the others are identical. The oscillator uses a 5963 twin triode, a ruggedized version of the 12AU7 tube. The oscillator, which is similar to the tone oscillator discussed in the preceding lesson, operates as a multivibrator. Section A of the tube is the basic oscillator, with section B acting as a feedback amplifier and phase inverter. The vibrasender is in parallel with the feedback voltage from the plate of tube section B to the grid of the oscillator; only that frequency which corresponds to the natural vibrating frequency of the reed can produce oscillation. The vibrasender has a very high effective Q and it maintains a high degree of frequency stability.

Capacitor C202 between the two plates provides negative feedback, which reduces the harmonic content and makes the output waveform nearly sinusoidal. The oscillator output is taken from across the plate circuit of section B, and an isolating resistor and capacitor are connected in series with a potentiometer, the output of the oscillator being controlled by the adjustment of the potentiometer. Each oscillator has a separate output voltage control. A Master

Tone Control, located near the individual tone output adjustments, determines the voltage applied to the amplifier, thus regulating the amount of modulation voltage to the transmitter. The output of the tone oscillators is terminated at the switches on the control panel. Each tone is connected to its two corresponding switches, one each in the top and bottom rows.

The Complete Tone Path

The first two tones of a 4-tone QUIK-CALL transmission are selected on the upper row of buttons, switch S105 in figure 4. This switch is mechanically designed so that only two buttons may be depressed at any one time. The tone with the lower number is applied to contact 5 of relay K101, and the second tone to contact 7.

When relay K101 is energized, the tones are combined (relay contacts 6 and 8 are tied together) and reach contact 12 of relay K1 in the timer circuit. When relay K1 is operated, the tones are applied through contact 11 of the relay to the Master Tone Control, R43. Resistor R43 applies all or some portion of the tone voltage to the audio amplifier, V2.

The output of the amplifier is available at terminals 7, 8, 9 and 10 of terminal board TB1. The connection to terminal 7 is completed only when relay K3 is operated. Terminals 7 and 8 supply a small output voltage with an impedance of 125 ohms. The same voltage and impedance is present at terminals 9 and 10, but the voltage at terminals 9 and 10 is connected directly to the output transformer and does not depend upon the contacts of relay K3. Output terminals 7 and 10 are used for a larger output voltage, at an impedance of 500 ohms, when a jumper is connected between terminals 8 and 9.

A meter on the control panel is used to monitor the level of the tones being sent to the transmitter. Calibrated in decibels, this meter is connected across the full output of the amplifier and indicates the relative amplitude of the tones.

The path for the tones selected from the lower row of buttons (S106) for the second pulse is similar to the path for the first pulse except that they reach the amplifier by passing through contacts 1, 2, 3 and 4 of relay K101 and contacts 6 and 7 of K2.

The Audio Amplifier

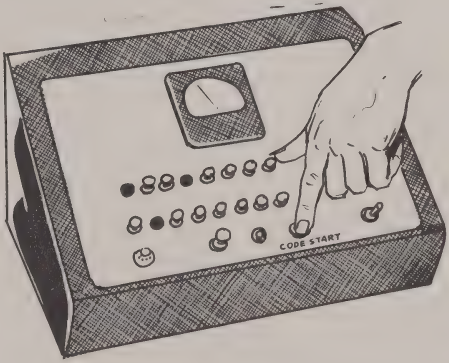
The audio amplifier provides the necessary amplification for the audio tones to give them sufficient amplitude to modulate the transmitter. A single 5963 type tube is used for both stages of the amplifier.

The left-hand section of the tube is the first stage. Its cathode bias resistor is unbypassed in order to provide negative feedback, thereby improving the frequency response. Resistor R26 is the plate load, with the output capacitively coupled (C8) to the grid of the right-hand section. This section also uses an unbypassed cathode bias resistor. Still further improvement of the frequency response is realized by means of the feedback capacitors (C6 and C7) between the plates of the two triode sections.

The transformer has a split secondary, each winding an impedance of 125 ohms. When these windings are connected in series (by placing a jumper between terminals 8 and 9 at the terminal board), the total secondary impedance is 500 ohms. For applications requiring output voltages between 0.5 and 1.5 volts, connections are made to terminals 7 and 8 of the terminal board; for an output of from 1 to 3 volts, terminals 7 and 10 are used. Where less than 0.5 volt is desired, a voltage divider consisting of resistors in series and having a total resistance of 500 ohms is connected between terminals 7 and 10, with the output taken from the appropriate point on the divider. When using any of these connections, it is necessary to install a jumper between terminals 8 and 9.

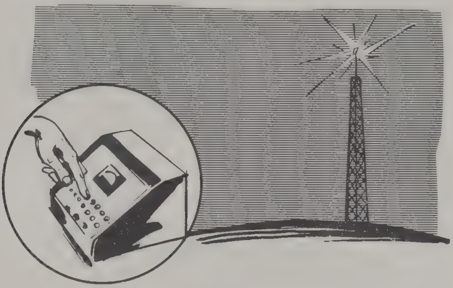
First Tone Pulse

To transmit a QUIK-CALL signal, the operator first depresses four buttons, two in the upper row and two in the bottom row. He then pushes the "code start" button, holding it down until the red indicator lamp goes on, which happens in less than one second. The operator may now release the "code start" button. The transmission of the proper QUIK-CALL tones will be performed automatically. Let us now analyze the operation of the equipment during the transmission of the first pulse. In order to make it easy to follow this first tone pulse operation, the circuit is printed in red in figure 4.



Quik-Call Code Tones are Automatically Operated, Timed and Transmitted as Soon as the Operator Depresses the Code Start Button.

We have already traced the path of the tones selected by the buttons in the upper row (switch S105). For these tones to reach the modulator, it is necessary to energize relay K1, which in turn operates relays K101 and K3. When the "code start" button is depressed, the 250 volt (B++) supply is applied to the grid of timer tube V1A, making that tube conduct heavily. Here is how this is accomplished. Terminal 2 of the start switch (S101) is connected to B++. This voltage is applied through switch contacts 1 and 2 to the grid of circuit of V1A. Capacitor C4 is in series with the grid resistor R8, but the full supply voltage is impressed across the resistor the instant the switch contacts engage.



Quik-Call Allows for Remote Control by Radio. Here a Distant Tower Light has been Turned On.

The cathode return path is through the coil of relay K1 to the positive side of the 8-volt bias supply. This voltage does not initially bias the tube to cut-off but, without the positive pulse at the grid, the cathode current is too small to energize the relay. As soon as the positive pulse is applied to the tube grid, however, the tube conducts heavily and the relay energizes. As we know (from the simplified sketch of figure 2), this controls the transmission of the first two tone pulses.

The holding of relay K1 for 0.75 second is accomplished in connection with the operation of relay K3. When relay K1 operates, its contacts 4 and 5 close, applying 250 volts to the coil of relay K3. (Resistor R20 limits the current in the relay coil to the proper amount.) Before relay K3 is energized, its contacts 9 and 10 are closed, completing a path for charging capacitor C2A. The complete circuit is through resistor R21 and contacts 8 and 9 of relay K2. Thus, before relay K3 energizes, capacitor C2A has been charged to 250 volts.

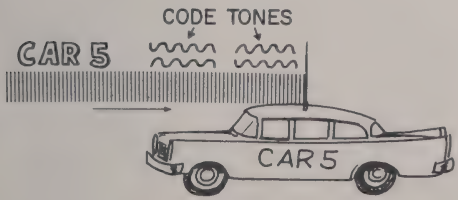
When K3 is operated by the action of relay K1, capacitor C2A is connected into the grid circuit of V1A through relay contacts 10 and 11. This positive charge maintains V1A conductive for approximately 0.75 second, and controls the timing of the first pulse. The pulse duration can be changed by using one of the alternate resistor connections (R7-R10) in the grid circuit of V1A. A large resistance produces a longer pulse. A small resistance permits a faster discharge of C2A, and hence a shorter pulse results.

Relay K1 has several other functions besides operating relay K3. The closing of contacts 11 and 12 completes the path for the tones to the grid of the amplifier. Contacts 6 and 7 are used in connection with remote operation. (This ground circuit discontinues the operation of the equipment from the remote position.) Contacts 1, 2, 3, 8, 9 and 10 are for the control of the second pulse and will be discussed shortly.

When relay K3 energizes, several other functions are provided besides the holding of relay K1. The closing of contacts 1 and 2 applies 250 volts (1) to the red indicator lamp on the selector panel and (2) through contacts 3 and 4 of the code start switch, S101, to the coil of relay K101. Relay K101 then closes, applying the audio tones to the amplifier. In order for relay K101 to become energized, however, the code start button must be held down (for a fraction of a second) until the indicator lamp lights, indicating that B++ has been applied to K101.

Three pairs of normally open contacts on relay K3, connected to terminals 1 through 6 of the terminal board, are used respectively (1) to operate the transmit relay of the transmitter, (2) to mute the microphone during code tone transmission, and (3) to perform any other similar function. When contacts 12 and 13 of the relay close, they complete the audio output circuit from the amplifier to the modulator. Contacts 14 and 15 are used to apply 6.3 volts AC to remote equipment for certain control purposes.

So much for the operation of the first tone pulse. The tones selected in the top row of buttons are sent to the amplifier, reach the modulator stage of the transmitter, are placed "on the air," and finally reach the receiver. This pulse is transmitted for a period of 0.75 second, during which time relays K1, K3 and K101 remain energized.



Quik-Call Operation Depends upon Four Coding Tones Sent at the Beginning of the Transmission.

Pulse Spacing

For the proper operation of QUIK-CALL equipment, it is essential that the second set of pulse tones be delayed for a short period of time, 0.2 second being sufficient. Unless this is done, receivers having the same coding tones, but in a different order, will respond to calls not meant for them. This condition arises as a result of the continued vibration of the vibrasponder reeds in the receiving equipment for a short time after the tone transmission has been discontinued. It is thus necessary to insert a short interval of no modulation after the first pulse, to permit the reeds in the vibrasponders to stop vibrating. After 0.2 second the reeds will have damped to such an extent that contact will no longer be made.

The required spacing is accomplished by the discharge of two capacitors, C3 and C2B, into the grid circuit of V1B. During the first pulse (while relay K1 is energized), capacitor C3 is charged to 250 volts, with its "right-hand" side (as shown in figure 4) positive with respect to ground. (The left-hand side of the capacitor is grounded through relay contacts 9 and 10.) Capacitor C2B is also charged to 250 volts, through relay contacts 2 and 3.

As soon as relay K1 releases, these two capacitors are connected so that they discharge through R16, the grid resistor of the second pulse timer, V1B. The positive side of C2B is connected to the grid through contacts 1 and 2, while the negative side of C3 is connected to the grid by the action of contacts 8, 9 and 10 of the relay. The negative charge on C3 is applied to the grid directly, but the positive charge (on C2B) is "delayed" by the series connected resistor R14, which makes the time constant of this circuit much longer than that of C3.

Thus, the grid of V1B first becomes negative, remaining so for a short period of time. As capacitor C3 discharges quickly, the grid soon becomes less negative. At the same time, capacitor C2B discharges through R14 and R16, forcing the grid to swing positive. Within 0.2 second, the grid reaches the point where V1B conducts, operating relay K2 in its cathode circuit.

During the brief interval between the end of the first pulse and the beginning of the second pulse, it is necessary for relays K3 and K101 to remain energized. Relay K101 will remain energized as long as relay K3 is energized. Relay K3 supplies 250 volts to terminal 13 of relay K101, and with contacts 12 and 13 closed, this 250 volts is applied to its coil, thereby locking the relay. The only way in which this relay will now open is to remove the 250-volt supply by releasing relay K3. Relay K3 is held closed between pulses by the charge that has accumulated on capacitor C5. (When relay K1 is energized, C5 charges to 250 volts through contacts 4 and 5.) When relay K1 releases, this capacitor discharges through the coil of K3, keeping this relay energized.

Second Tone Pulse

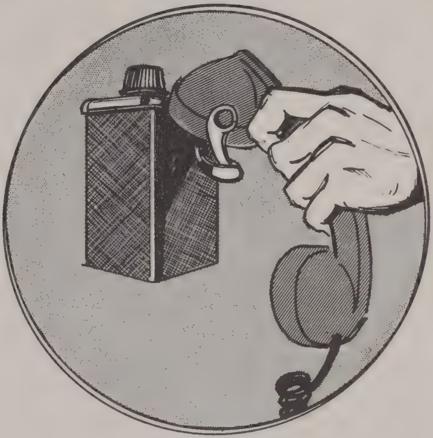
As soon as the second pulse begins, relay K3 is operated through the contacts of relay K2. We have already seen the basic operation of relay K2 (figure 3). This relay performs several functions. For one thing, it causes K3 to operate. This is accomplished by means of contacts 9 and 10 (of K2) which apply 250 volts to the coil of K3. Contacts 6 and 7 of K2 close, completing the path for the tones to the audio amplifier. This path is also completed by closed contacts of relay K101 (but this relay, we know, is being held closed by K3). Contacts 11 and 12 of K2 close, completing the grid return to ground through resistor R11. This smaller grid resistance establishes the correct timing circuit for the grid of V1B. Before relay K2 can release, capacitor C2B must discharge. The path is now through R11, and this time constant is correct for the second pulse. In the meantime, contacts 2 and 3 of K2 also close, charging capacitor C1B to 250 volts. We shall see the purpose for this later.

After 0.75 second, C2B no longer holds the grid of V1B sufficiently positive for its cathode current to operate relay K2; as a result, K2 releases. When K2 releases, K3 and K101 also release. The transmission of the second set of code tones is now completed. The red indicator lamp goes out, the meter on the selector panel reads zero, and the transmit-receive relay (in the two-way equipment) also releases, placing the equipment in standby (receive) condition. If the operator wishes to send a message, however, he may use the mike button (or foot switch) to keep the transmitter on the air after the tone transmission is completed.

Selector Button Release

Provision is made for the operator to release any buttons that may be depressed, at any time. An "AUTO. REL." (automatic release) switch also provides for releasing the buttons automatically at the termination of the second pulse.

The manual "RELEASE" switch, S102, normally connects the 250-volt supply line to capacitor C101 and the capacitor is usually fully charged. As soon as this "release" button is depressed, however, the capacitor is connected to the coil of the "button release solenoid" (L101). The solenoid immediately releases both rows of selector buttons.

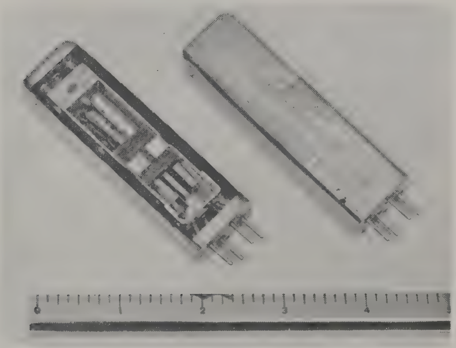


Lifting the Handset from the Hang-Up Box Stops Quik-Call Operation and the Receiver Operates in a Normal Manner.

Automatic release is accomplished by capacitor C1B through contacts 1 and 2 of relay K2. When this relay is energized during the second pulse, the capacitor is charged to 250 volts through contacts 2 and 3. When the relay releases at the end of the second pulse transmission, this charged capacitor is connected (through contacts 1 and 2) to the "button release solenoid." The functioning of this circuit requires switch S104 to be in its automatic position. Also, relay K101 must be energized, for the path is through its contacts 10 and 11. (It is normal for this relay to remain energized for a short time after relay K2 releases.) If the switch is not in the "AUTO. REL." position, the manual "RELEASE" button must be used.

Group-Call

Besides alerting a single station within the system by means of the 4-tone, 2-pulse system, it is also possible to make a call simultaneously to a group of stations within the system. Two tones are necessary for group-call, and they are selected on the bottom row of buttons. Instead of pushing the code start button, the "group-test" button is now depressed. The timing of this transmission is now no longer automatic. Instead, the timing is up to the operator, and for this operation he must keep the button down for approximately four seconds in order to properly alert the desired stations.



Quik-Call Code Tones are Controlled by Vibrasenders, the Same as in Private Line Systems.

When the "GROUP-TEST" switch (S103) is closed, the 250 volts available at switch contacts 1 and 3 is applied to the coils of relays K101 and K2. The contacts of relay K101 complete the tone path to the contacts of relay K2, and with relay K2 operated, the tones reach the audio amplifiers. Because K2 is operated, relay K3 also closes. Relay K3 completes the audio output circuit to the modulator, causes the indicator lamp to light, turns on the transmitter, and mutes the microphone. The group-call tones are transmitted for as long as the operator holds down the group-test button. After four seconds, however, the receivers should be alerted. The desired message may now be sent.

Meanwhile, at the Receiver . . .

The basic QUIK-CALL section of the receiver is shown in figure 5. Depending upon the switch in the hang-up box, the audio at the secondary of the output transformer may be applied to the speaker or it may be applied to the QUIK-CALL unit.

If the microphone or handset is off the hook, the audio (available at terminal 46) is applied through contacts D and C of the switch to terminal 45. From terminal 45 the path proceeds through jumper JU-1 to the speaker. Thus, if the hook in the hang-up box is "up," the receiver output will be applied directly to the speaker. QUIK-CALL control is possible only when the handset or microphone is on the hook.

In normal QUIK-CALL operation, then, the audio path does not lead directly to the speaker as described above, but rather through contacts D and E of the switch to terminal 42. From terminal 42 the audio goes to terminals G and F of relay K1 and on to the four vibrasponder coils.

The only way in which the audio can now reach the speaker is for the relay to be operated. The audio then finds a path to the speaker through relay contacts F and E. The relay is energized only if the correct tones are received. When this occurs, the vibrasponders complete the circuit (partly shown in the figure), which causes the tube to conduct and operate the relay.

The length of time that the relay remains energized depends upon the position of the "lock-nonlock" switch. With the switch in the "nonlock" position, the timing circuit will keep the relay operated for about 7 seconds; in the "lock" position, the relay stays energized until the operator removes the mike from its hook.

With a QUIK-CALL signal coming into the receiver, the pulses quickly capture the circuit and cause the relay to close. The operator will usually hear the end of the second pulse transmission. Or, if the received signal is weak so that the second pulse just opens the receiver at the end of the pulse, the operator will hear the squelch tail (if the operator at the base station does not keep the transmitter "on the air"). In this way, the operator is alerted to an incoming message before the message is actually sent.

If the operator does not complete his message during the seven seconds following the second pulse, and if the operator at the receiver does not remove his microphone, the relay opens at the end of this period, and the receiver is effectively "dead." (We are assuming that the function switch is still in the nonlock position.)

If the receiver QUIK-CALL switch is placed in the "lock" position, however, once the relay has been closed by the tone pulses the relay will remain locked-in until the operator removes his microphone from the hook. The lock-in position of the switch places the grid at near-cathode potential, through relay contacts A and B, thereby allowing the tube to conduct until the microphone is removed. With the microphone off the hook, the right-hand terminal of the relay coil is grounded through its contacts A and B, and contacts A and B of the hang-up switch. With both terminals of the relay coil grounded, the relay releases.

Terminals C and D of the relay "make" when the relay operates, and they can be used to close a circuit which operates a horn, lights a lamp, or performs a similar function. Thus the operator who has been away from the receiver knows that he has been called. For this function, the switch must be placed in the "lock" position.

The Vibrasponder Circuit

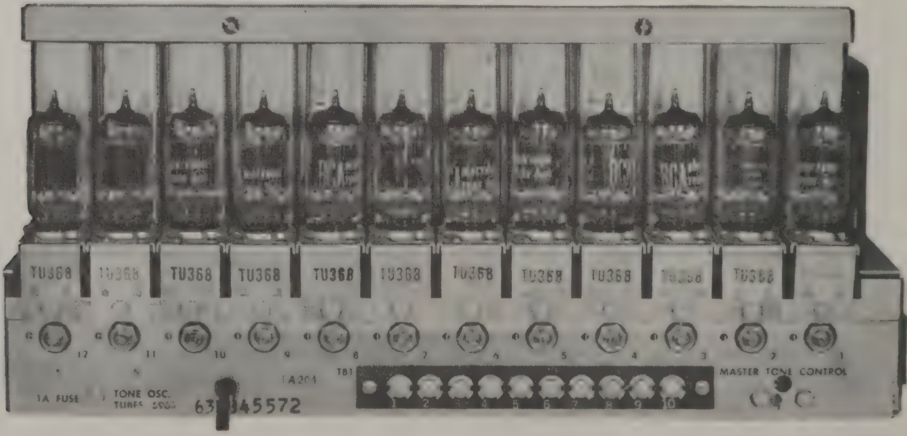
Figure 6 is a complete diagram of the QUIK-CALL unit required at the receiver. For QUIK-CALL operation, four vibrasponders control the conduction of the tube, V1, and the latter determines the operation of control relay K1.

Both triode sections of V1 are initially biased so that there is but little conduction. Relay K1 in the cathode of the right-hand section will not operate, therefore, unless that triode section is made to conduct heavily. This is accomplished by making the grid positive. As we shall see, this positive voltage originates at the plates of V1.

The QUIK-CALL tones from the receiver output transformer are applied to the four coils of the vibrasponders through contacts F and G of relay K1. The tones of the first pulse must correspond to the frequency of the vibrasponders installed at E1 and E2. Assuming that this is the case, the reeds of these two vibrasponders close their "B" contacts.

Although the reed contact is intermittent, the action of the RC circuit in parallel with the contacts produces an almost steady DC voltage as the reed continues to vibrate.

The B+ voltage (present at the plates of the tubes) is applied through the vibrating reed contacts of both vibrasponders to the grid circuit of the left-hand triode. This voltage is applied to the junction of resistors R1 and R2, and charges the grid capacitor, C1, to a high DC voltage. The discharge of this capacitor, however, is through R1 and R2 in series, so that the time constant is long and the grid is kept positive for some time.



Here We See the Twelve Tone Generators, Vibrasenders, and Level Setting Adjustments, all Part of the Quik-Call Base Station.

When the grid of the tube swings positive, the tube conducts heavily and almost all of the supply voltage appears across the large cathode resistor, R3. This high positive voltage is used to unbias the grid of the right-hand triode.

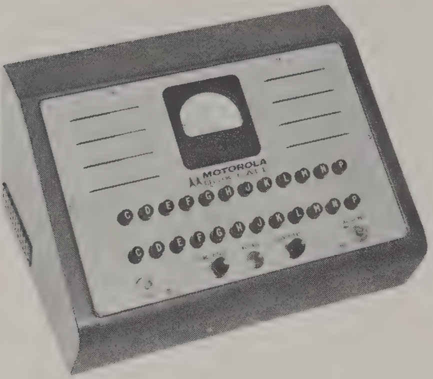
Assuming that the second pulse corresponds to the frequencies of vibrasponders E3 and E4, contacts "B" of both these vibrasponders close. The positive voltage from the cathode of the first triode then charges capacitor C2 in the grid circuit of the right-hand triode. This makes the grid positive and the tube conducts. The cathode current passes through the coil of relay K1, causing the relay to operate. The charged capacitor (C2) in the grid of the triode discharges through the large resistor in parallel with it and, because of the long constant involved, the grid holds the tube conductive for about seven seconds (with the switch in nonlock position).. The relay contacts are closed during this time and the operator hears all messages that may be sent.

If the switch is in the "lock" position, however, the relay remains operated until the microphone is removed from the hangup hook. With the switch in the lock position, the grid is returned to the top of the relay coil through relay contacts A and B. After capacitor C2 has discharged, the only remaining bias on the stage is that developed by the small cathode resistor, R5. This allows the stage to continue to conduct normally and the relay remains energized. When the microphone is removed from its hook, the blue wire leading to terminal A of the relay is grounded; with contacts A and B closed, the top of the relay (terminal J) is grounded, so the relay must release.

Receiver Group-Call Operation

Only two tones, common to a group of receivers, are required for group-call. These tones must correspond to the frequencies of the vibrasponders installed in sockets E2 and E3 (fig. 6). To alert the receivers within a group, the operator sends these common tones for a period of four seconds. These group-call tones energize vibrasponders E2 and E3 at the receiver, closing their "B" contacts and applying the plate supply voltage to grid capacitor C2 through the contacts of vibrasponder E2, R7 (3.9 megohm), and the contacts of vibrasponder E3. The tones must be continuous for approximately four seconds, as it requires this much time for the vibrasponders to operate and for capacitor C2 to charge through the high resistance of R7. After four seconds, however, all receivers which have the proper group-call tones will have been alerted. The desired message may now be sent simultaneously to all the receivers of this group.

Where group-call operation alone is desired, only two vibrasponders need be installed in the E2 and E3 sockets. (In earlier models, the wiring of E2 and E3 was different



Here We See a Quik-Call Console Utilizing High-Frequency Coding Tones (Evidenced by the Letters on the Push-Buttons).

and all four vibrasponders were required to complete these circuits.)

Level Adjustments

Although the levels of the various oscillators used with QUIK-CALL equipment are adjusted at the factory, it is important that they be readjusted (checked) according to the requirements of the system being used. Transmitters may differ as to the modulation voltage required for the same amount of deviation, and control lines have various voltage drops. It is thus necessary to adjust the tone levels for a deviation which will produce sufficient voltage at the receiver output to operate the vibrasponders. In making any level adjustments, we are thus interested in the voltage produced at the receiver rather than in the modulating voltage to the transmitter.

The various vibrasponder assemblies at the receiver require different voltage levels to produce positive operation of the reed. These levels will be found in a chart such as that of figure 7.

At the back of the QUIK-CALL console there is an adjustment for each of the individual tone outputs, plus a master tone control. The output adjustment for the separate tones are numbered from 1 to 12 and correspond to the 12 tone generators, regardless of which vibrasender is installed in the socket.

If the particular system uses high-band tones (usually the case in almost all new installations), the first steps are (1) to adjust the individual tone level for tone number 12 (labeled "P") and (2) to adjust the master level for the desired receiver output. Then, leaving the master adjustment at one setting, we adjust the remainder of the tone generators for the recommended output.

An AC voltmeter is connected at the audio input to the QUIK-CALL unit, and the receiver is unsquelched (squelch control fully clockwise). The receiver audio level control (located on the receiver chassis--not the volume control on the control head) is advanced until the reading on the meter, due to noise, is between 0.8 and 1.0 volt. The receiver is then squelched and the level adjustment for tone 12 (P) is set to approximately three-fourths maximum. The master tone control is then adjusted for a reading of 2.2 volts on the meter. (The

squelch control is turned
fully counterclockwise

Here We See the 32-Button Accessory Box Connected to the Quik-Call Console.

master tone control should not be changed after this; the control for tone 12 also needs no further adjustment.) The individual tone levels may now be adjusted according to the voltage values indicated in figure 7.

Where low-band tones are used for a particular system, the level of tone number 1 is first adjusted by placing the individual tone control at three-fourths maximum and adjusting the master control to 0.70 volt. The individual levels are then adjusted according to the chart, as before.

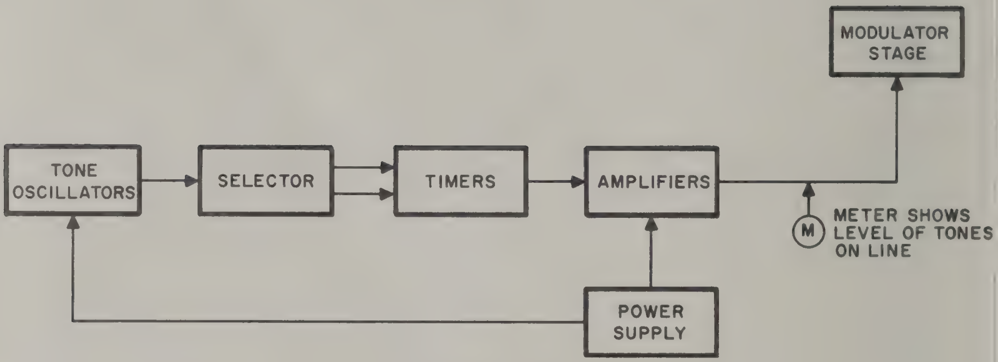
The meter on the QUIK-CALL selector panel is not to be used in adjusting the tone levels. This meter merely indicates the level of the voltage at the console. It does not show the amount of deviation produced nor does it tell how much voltage is applied to the vibrasponders at the receiver.

Accessory Selector Box

A 32-button selector box may be used as an accessory to the QUIK-CALL console described in this lesson. This additional selector box may plug directly into the console or it may be remotely located, with an interconnecting cable between the two units. This selector box facilitates the selection of QUIK-CALL groups or group-calls by requiring only one button to be depressed for any one call. Connections may be made so that one button will initiate a QUIK-CALL function (or a group-call) without any thought as to timing. The timing is performed by the circuitry within the selector box. This piece of equipment allows as many as 32 different calls to be made, requiring only one button to be depressed for each. A red indicator lamp shows when a transmission is taking place or when the console is being used.

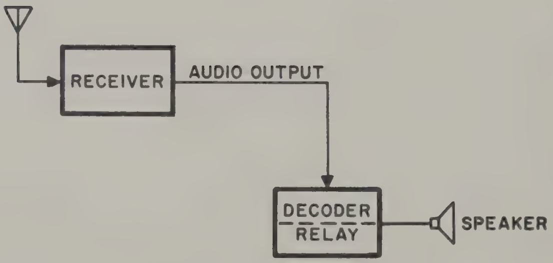
STUDENT NOTES

STUDENT NOTES



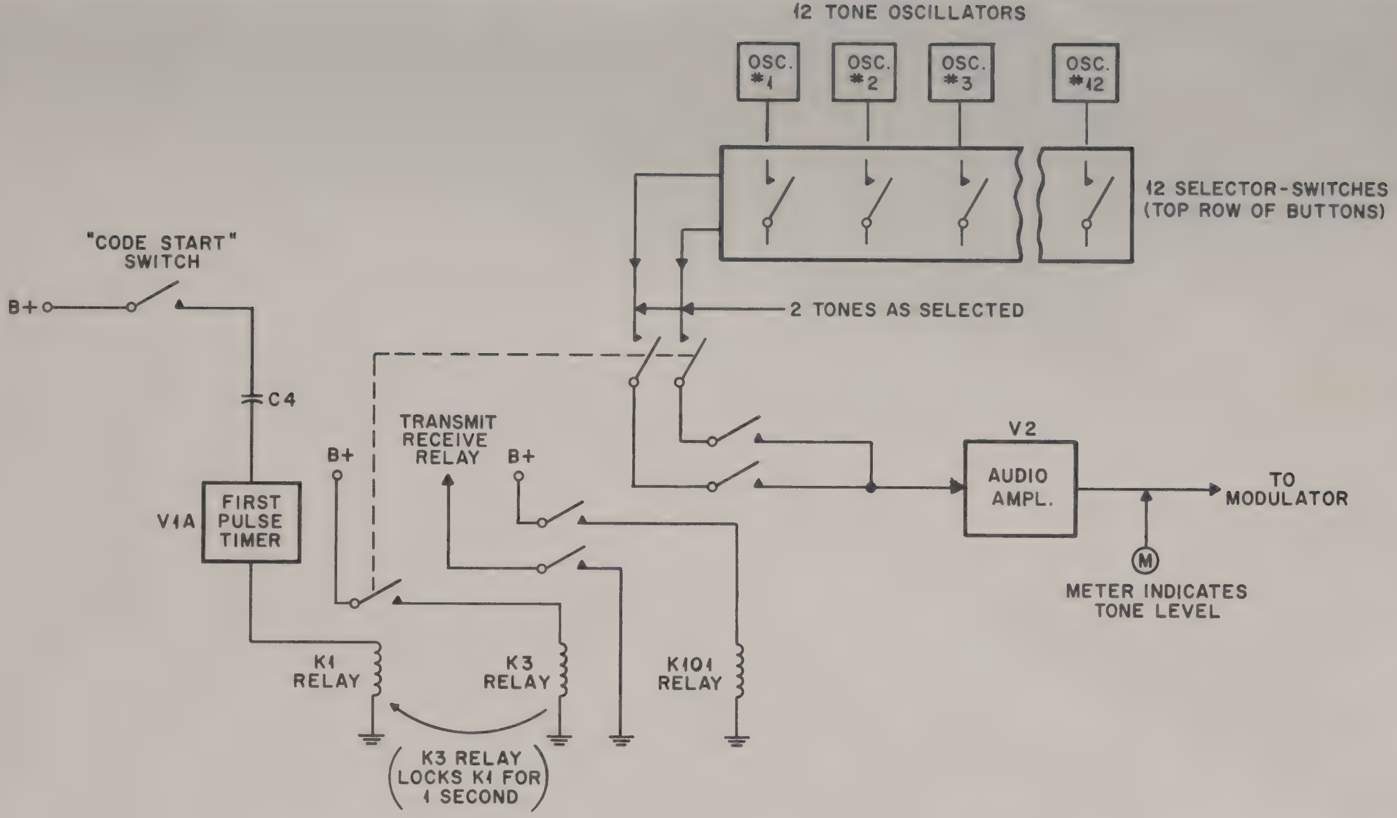
TRANSMITTER
QUIK-CALL SYSTEM

FIGURE 1A



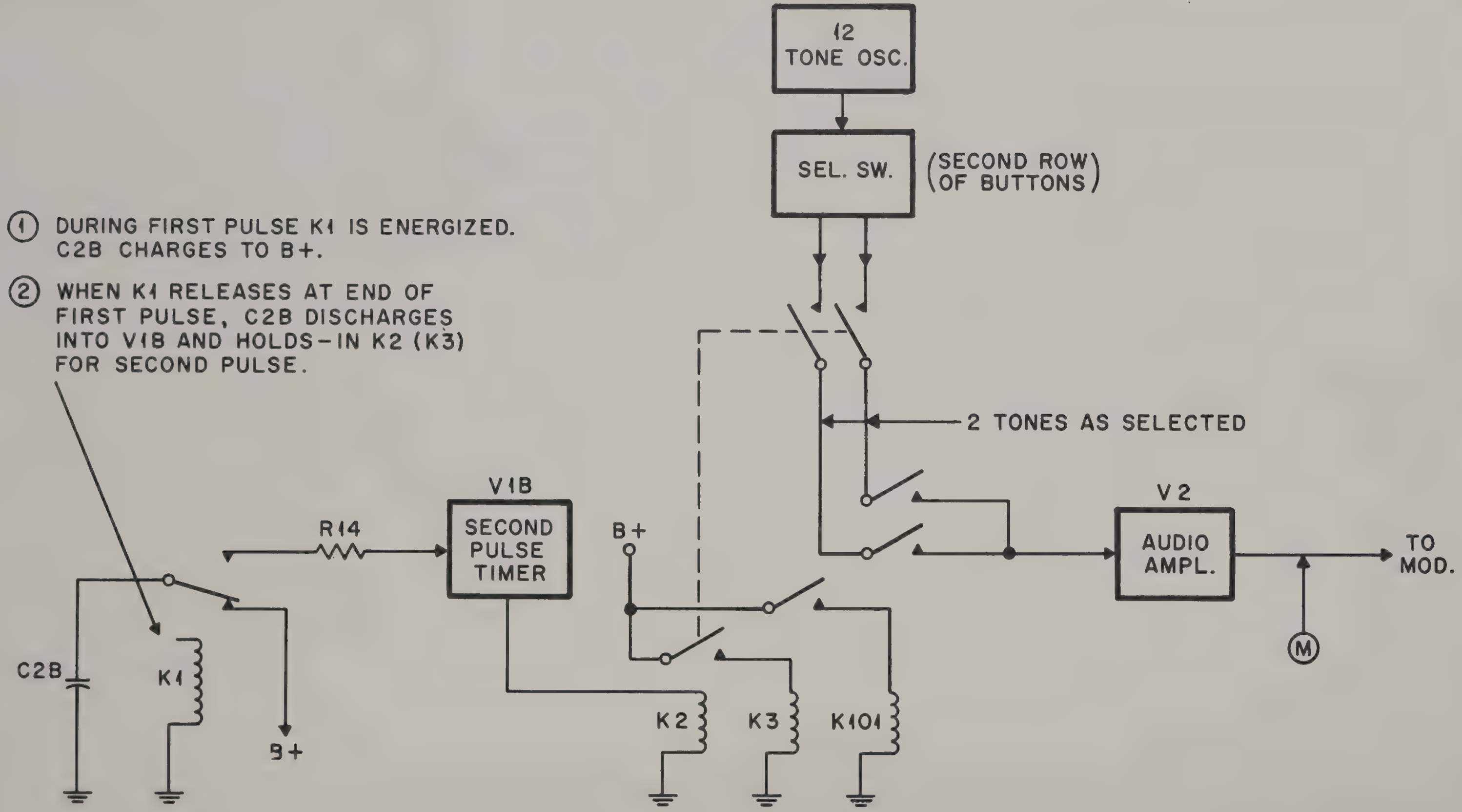
RECEIVER
QUIK-CALL SYSTEM

FIGURE 1B



FIRST PULSE TRANSMISSION

FIGURE 2



① DURING FIRST PULSE K1 IS ENERGIZED. C2B CHARGES TO B+.

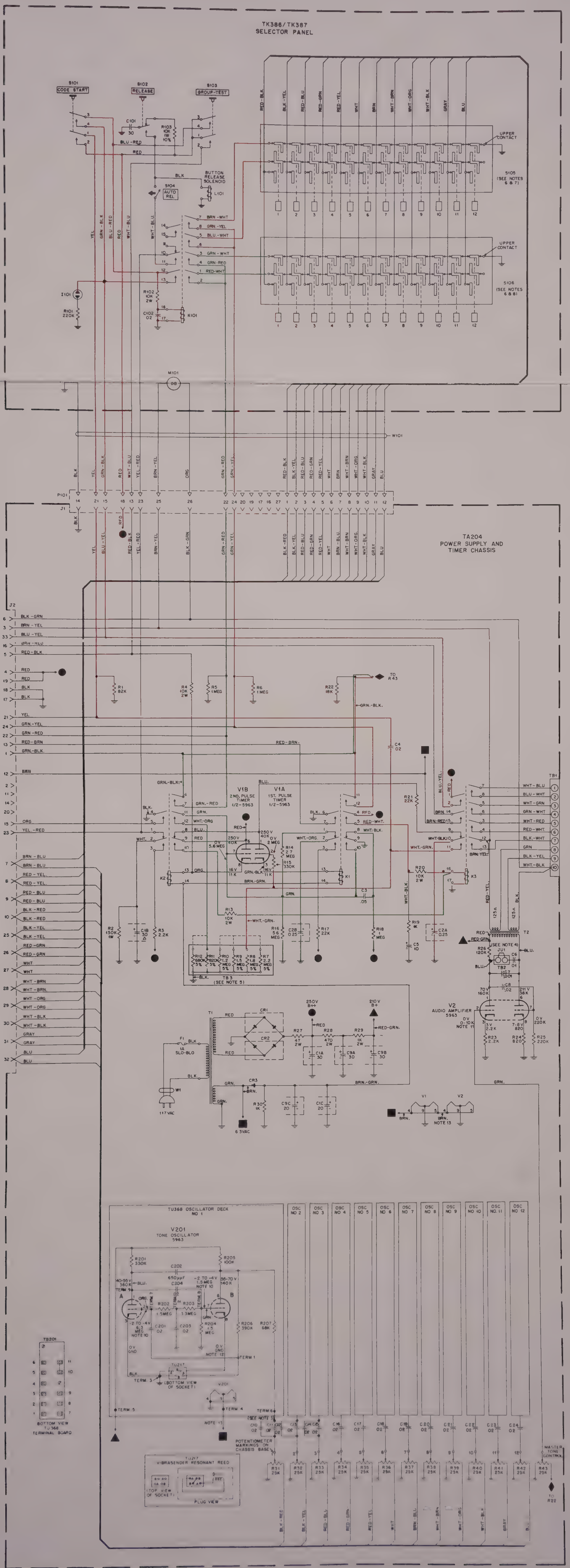
② WHEN K1 RELEASES AT END OF FIRST PULSE, C2B DISCHARGES INTO V1B AND HOLDS-IN K2 (K3) FOR SECOND PULSE.

SECOND PULSE TRANSMISSION

FIGURE 3

STUDENT NOTES

STUDENT NOTES



TA203 SERIES QUIK-CALL CONSOLE

FIGURE 4

TONE ADJUSTMENT TABLES

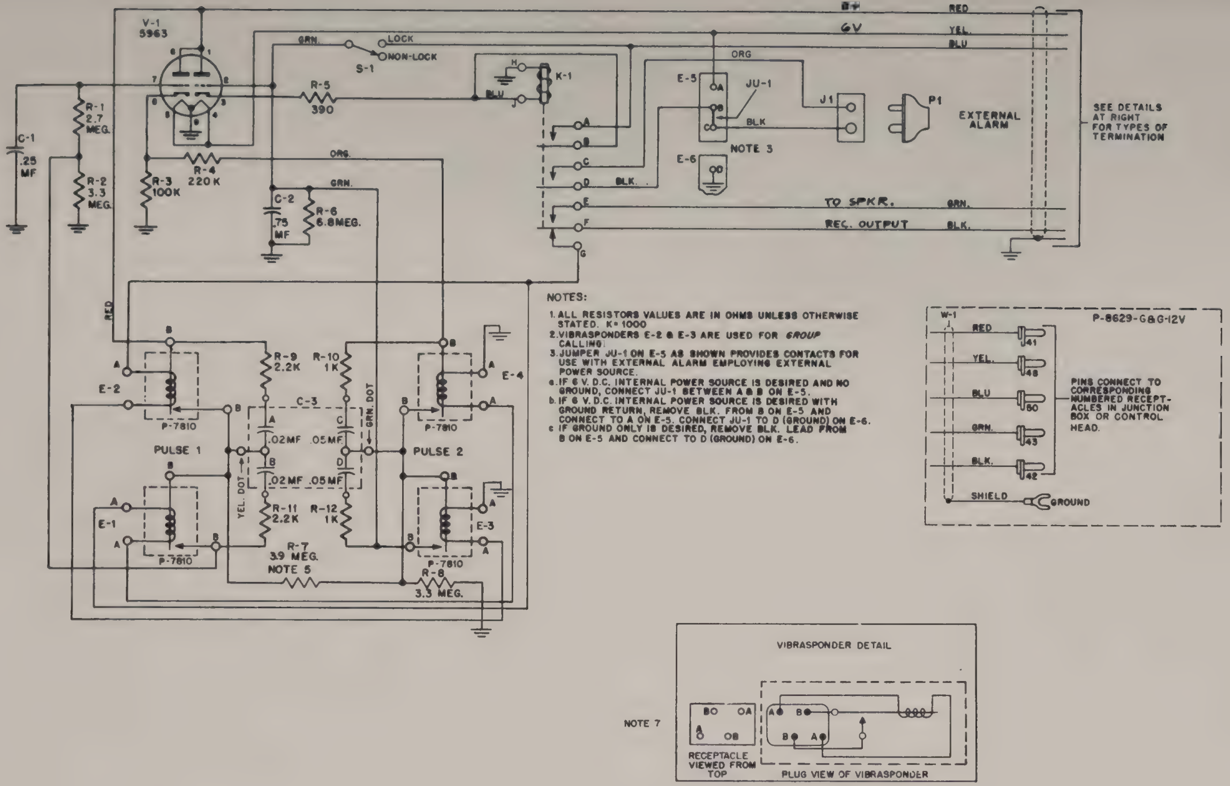
LOW BAND TONES (100 to 312.6 cps)

Push-Button	Tone Level Control	Voltage
1	1	0.70
2	2	0.62
3	3	0.53
4	4	0.53
5	5	0.53
6	6	0.58
7	7	0.65
8	8	0.72
9	9	0.79
0	10	0.88
A	11	0.98
B	12	1.08

HIGH BAND TONES (346.7 to 1084 cps)

Push-Button	Tone Level Control	Voltage
C	1	1.4 v.
D	2	1.5 v.
E	3	1.6 v.
F	4	1.7 v.
G	5	1.8 v.
H	6	1.9 v.
J	7	2.0 v.
K	8	2.1 v.
L	9	2.2 v.
M	10	2.2 v.
N	11	2.2 v.
P	12	2.2 v.

FIGURE 7.

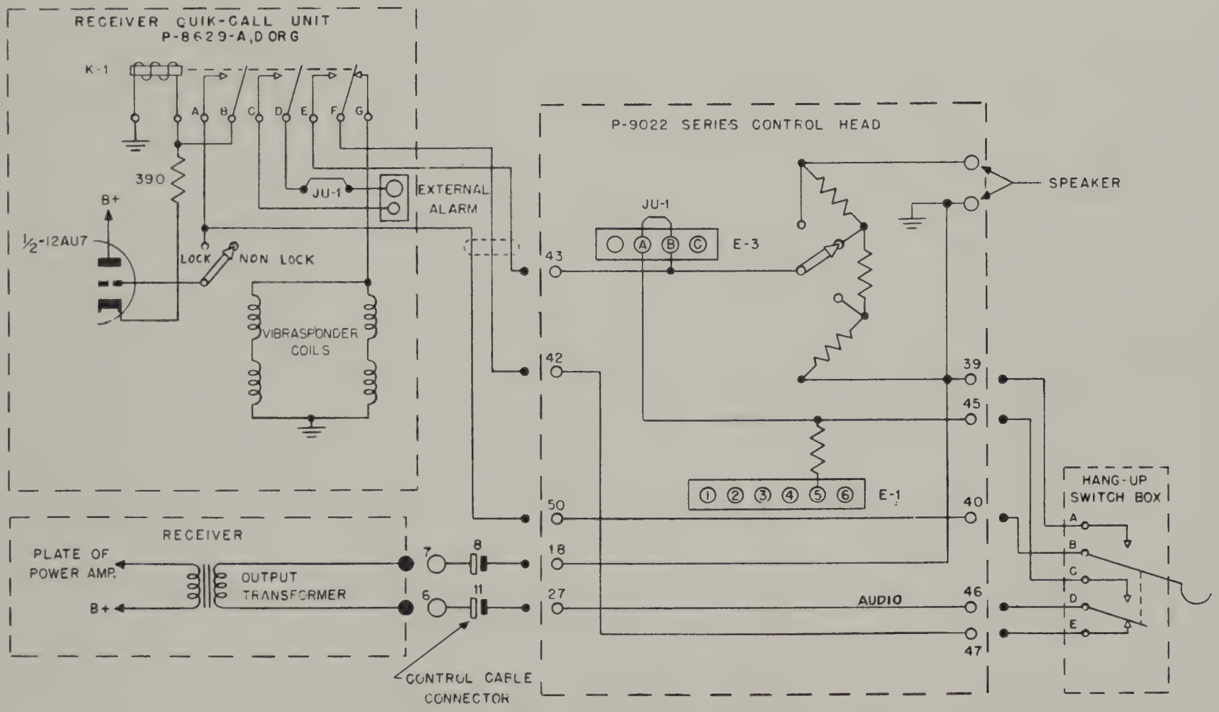


NOTES:

1. ALL RESISTORS VALUES ARE IN OHMS UNLESS OTHERWISE STATED. K= 1000
2. VIBRASPONDERS E-2 & E-3 ARE USED FOR *GROUP* CALLING.
3. JUMPER JU-1 ON E-5 AS SHOWN PROVIDES CONTACTS FOR USE WITH EXTERNAL ALARM EMPLOYING EXTERNAL POWER SOURCE.
a. IF 6 V. D.C. INTERNAL POWER SOURCE IS DESIRED AND NO GROUND, CONNECT JU-1 BETWEEN A & B ON E-5.
b. IF 6 V. D.C. INTERNAL POWER SOURCE IS DESIRED WITH GROUND RETURN, REMOVE BLK. FROM B ON E-5 AND CONNECT TO A ON E-5. CONNECT JU-1 TO D (GROUND) ON E-6.
c IF GROUND ONLY IS DESIRED, REMOVE BLK. LEAD FROM B ON E-5 AND CONNECT TO D (GROUND) ON E-6.

RECEIVER QUIK-CALL CONTROL CIRCUIT

FIGURE 6



NOTES:

1. THE MICROPHONE OR HANDSET IS SHOWN ON THE HOOK. SPEAKER CIRCUIT IS OPEN.
2. WHEN USING MILITARY MICROPHONE, JUMPER JU-1 MUST BE USED BETWEEN "A" & "B".
3. WHEN USING HANDSET, JU-1 BETWEEN "A" & "B" PUTS HANDSET IN PARALLEL WITH SPEAKER.
4. WHEN USING HANDSET AND NO JUMPER, HANDSET EARPIECE IS OPERATIVE AND SPEAKER IS MUTED EXCEPT FOR SELECTIVE CALL SIGNAL.
5. LETTER DESIGNATIONS ON HANG-UP SWITCH BOX ARE FOR REFERENCE ONLY.

RECEIVER QUIK-CALL
SIMPLIFIED CIRCUIT OPERATION
FIGURE 5

national

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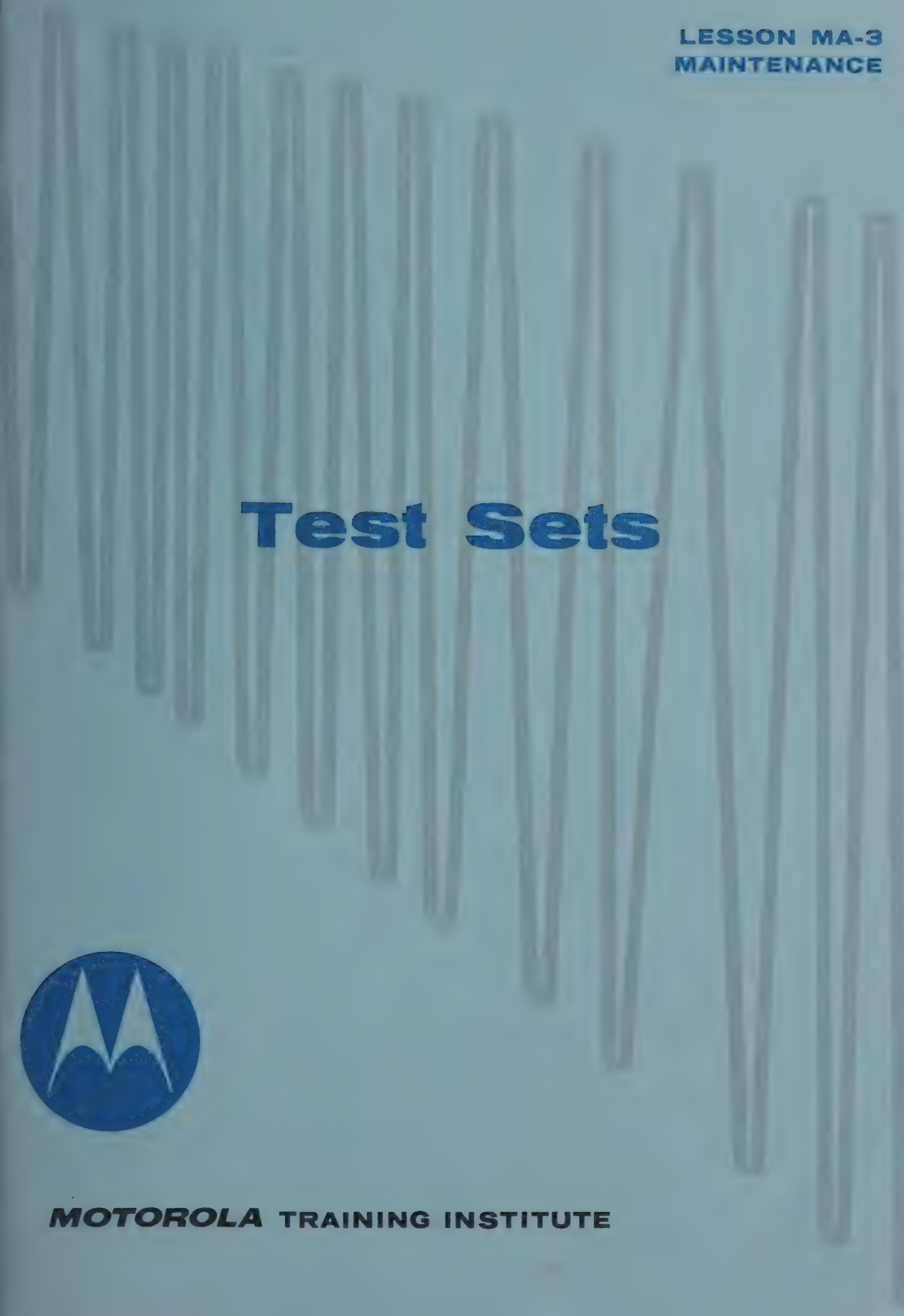
A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON MA-3
MAINTENANCE

Test Sets



MOTOROLA TRAINING INSTITUTE

A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON MA-3
MAINTENANCE

Test Sets

—one of a series of lessons on two-way FM communications—

MOTOROLA TRAINING INSTITUTE
4501 W. AUGUSTA BLVD., CHICAGO 51, ILLINOIS
APPROVED BY THE STATE OF ILLINOIS
DEPT. OF REGISTRATION AND EDUCATION

PREFACE

This is one lesson of a complete Motorola Home-Study Course which presents to the Service Technician both the principles of operation and the maintenance of two-way FM radio systems. The program covers mobile, portable and base station equipment, including the latest transistorized units.

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TEST SETS

LESSON MA-3

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NOTICE

Diagrams and figures referenced in text are "fold-outs" in back of each lesson, for use while studying. The Examinations are also there.

The large scale activity in constructing a nation-wide system of tollways, turnpikes and freeways has resulted in many new extensive communications systems. The special police and maintenance forces needed to protect and keep up these new traffic arteries rely heavily on two-way radio.

TEST SETS

Lesson MA-3

Introduction

Motorola has developed two test sets, both designed to provide quick and accurate checks on the various receivers and transmitters used in Motorola two-way communications equipment. These test sets are identified by their model numbers, P-8501 (A or B) and TU-546. The TU-546 is the newer of the two, but the P-8501 provides all the tests necessary for aligning and servicing the equipment. In this lesson we shall make a detailed analysis of the circuits within the test set, circuits which enable the serviceman to make all the necessary transmitter and receiver measurements. Let us begin with the P-8501 unit.

Functions Of The Test Set

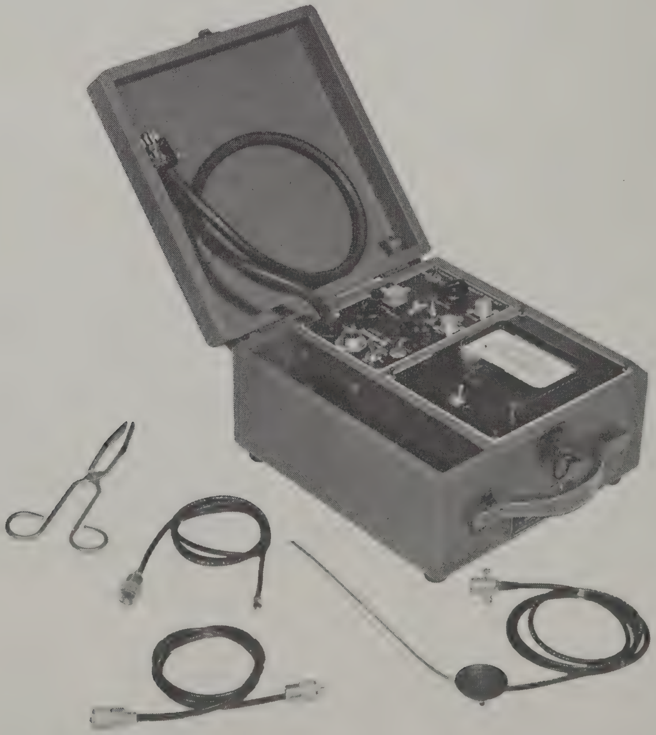
The P-8501 Motorola test set provides the following specific functions:

1. It meters the important circuits of the receiver. This is essential both for alignment and for the quick isolation of trouble within a particular section.
2. It meters the important circuits of the transmitter. By "viewing" the various circuits of the transmitter, the operation of each stage may be evaluated. In troubleshooting and in transmitter alignment, this function is essential, providing vital information to the serviceman.
3. It operates as a crystal-controlled signal generator. When equipped with a crystal of the correct frequency, the generator supplies an output which can be used for aligning or peaking the receiver circuits. For the RF circuits, a multiplier stage within the test set supplies the required signal at the channel frequency. For IF alignment, a crystal of the IF frequency is used.
4. It serves as a microammeter. The basic sensitivity of the meter in the test set is 50 microamperes for full-scale deflection. With an internal impedance of 2000 ohms, it takes 0.1 volt to produce full-scale deflection.
5. When used with the Motorola dummy antenna, the test set provides a means of measuring the power output of a transmitter.

6. It serves as a field strength meter. It can be used to measure relative signal strengths radiated from a transmitter antenna.

The Motorola test set is powered by self-contained batteries, and all functions of the unit are regulated by the controls on the front panel. Adapter cables enable the test set to be used with all Motorola equipment. The meter movement is protected by a 1/200 amp. fuse.

Figure 1 shows the front of the P8501 A/B test set. The various switches and controls are identified by numbers, corresponding to those on the schematic diagram (figure 2). Other connections are identified by letters for convenience of reference. The complete schematic diagram may seem complicated, but when the individual circuits corresponding to the various functions of the instrument are considered separately, the analysis can be made with ease. Before studying these



Here We See the Complete Motorola P-8501 Test Set, Including Accessories.

individual circuits, however, let us first examine the various front panel controls.

Function Switch (Grid Current-Meter-Field-Strength)

Designated as S1, this switch may be considered as the function switch. When the switch is in the meter (center) position, the test set can be used for metering the receiver or transmitter. In the GRID CURRENT position (left), the meter is connected so it will measure the oscillator grid current of the signal generator. Thus the meter is used in this position only when the oscillator is to be adjusted. In the FIELD STRENGTH position (right), the test set can be used to measure field strength. The input to the test set is at the PROBE connector (C) for this function.

Rec.-XMTR-0-50 MA Switch

This switch is designated as S4 on the schematic. With the function switch (S1) in the METER position, (as shown in figure 2), switch S4 determines whether the meter is to be used to monitor the receiver, the transmitter, or as a straight 50 ua DC meter.

The Position Switch

Designated S2 on the schematic, this 9-position switch selects the particular receiver or transmitter circuit to be metered. The fifth position is labeled both "PA" and "+4" on the panel. When the test set is being used with a receiver, this position is read as +4; with a transmitter, it is read as PA.

For monitoring either the receiver or the transmitter, the terminals of this switch are connected by means of a cable on the test set to the meter plug, P1. This plug is inserted into either the receiver or the transmitter - - - according to which is being metered.

XMTR. On Switch Microphone Receptacle

This spring-loaded switch is labeled S3 on the schematic. It provides for turning on the transmitter, by means of the test set. Because of the spring loading feature, the transmitter will be on only so long as the switch is held at the ON position. A microphone can be plugged into the mike receptacle (E) on the Test Set and used for the same purpose.

On/Off, Attenuator, Adj., Osc. Tune, XTAL, R.F. Out, and 6-12

These controls and receptacles are grouped together in the above heading because they are concerned with the operation of the signal generator portion of the test set. The ON/OFF switch (S6) connects the internal batteries to the oscillator and multiplier stages. Two crystal sockets (A and B) are provided for connecting frequency-control crystals into the oscillator. The generator output is available at the RF OUT. receptacle (D). The amount of RF voltage at the output is controlled by the ATTENUATOR (R9), which varies the output between maximum and zero. The ADJ. (C2) and OSC. TUNE (L1) controls are used in tuning the generator for correct frequency and maximum output voltage.

Filament voltage from the receiver is available for crystals equipped with heaters. The 6-12 switch (S5) provides for the proper heater voltage at the heater. This switch shorts out a series dropping resistor when 6-volt supply is used. With a higher filament voltage (12 volts), the series resistor reduces the voltage to the proper value at the crystal heater.

Meter Reversing Switch

When the service technician wishes to use the Motorola test set for measuring the circuits within a receiver, he first operates the switches as follows: function switch S1 to METER, switch S4 to REC, meter reversing switch (S7) to "—," its normal setting. The various circuits within the receiver may now be metered according to the setting of the position switch (S2). The meter plug (P1) is then inserted into the receiver receptacle. The leads of the various circuits to be measured are already connected to these terminals, within the receiver.

Metering The Receiver

Figure 3 shows the complete circuitry of the receiver metering function. Metering plug P1, to the right, connects into the receiver chassis, and the various circuits of the receiver are then connected to the meter according to the setting of the position switch, S2. The position switch has two decks or sections, designated A and B.

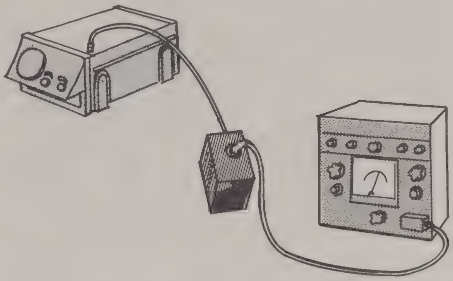
In position 1 the voltage present at plug terminal 1 is applied through section A of the switch, through function switch S1 (in METER position), through the meter reversing switch S7, through the RF choke (RFC2) and through the fuse to the negative side of the meter movement. The positive side of the meter is returned to ground through RFC1 and the meter reversing switch, the function switch (in METER position), the 17.5K resistor, and section B of the position switch, S2. Thus, in position 1 the meter is connected to measure a voltage which is negative with respect to ground.

Positions 2, 3, -4, 5 and 6 of the switch establish the same circuit through the meter as used for position 1. Therefore, these positions are also used for metering negative voltages.

When the test set is used with a receiver, positions 1, 2, and 3 are usually reserved for measuring negative voltages produced by limiting action. This may be in the limiter grid, or in the grids of the preceding IF stage producing limiting action. Position -4 is used to zero the discriminator transformer secondary. We know from our previous study that the discriminator output may be either positive or negative depending upon the tuned secondary; only when the secondary is tuned to its exact center frequency will the reading be zero. If the output should be positive the meter reading will be downward when the switch is in position -4. Under these conditions the meter reversing switch (S7) may be placed in the (+) setting, or the position switch (S2) may be set at "+4." The +4 circuit is the same as that of -4, except the current goes through the meter in the opposite direction.

Position 5 of the meter is used for adjusting the primary of the discriminator transformer to center frequency. Position 6 is used to meter the grid voltage in the high-frequency oscillator; it thus becomes a means of adjusting the oscillator for maximum activity.

With certain Motorola equipment, exceptions will be found in the application of the various switch positions. This is particularly true with the 450-mc line, where position 3 may be used to measure the high-frequency oscillator grid current, the position switch being used for the multipliers following the oscillator.



Used With the Motorola Dummy Load, the Test Set Measures Transmitter Power Output.

In 450-mc equipment a number of multipliers are used to produce the desired harmonic, and these multipliers must be tuned. Several additional multiplier readings are thus required, and for some receivers the necessary connections are made to terminals 7 and 8 of the receiver receptacle with meter plug terminals 4 and 5. With the adapter plug in use, the multipliers are thus tuned in positions -4 and 5, respectively. In other receivers, positions -4 and 6 are used to meter the multipliers. (The schematic of adapter plug appears at the bottom of figure 2.)

Position 7 is used with but a few receivers, which make use of this connection for measuring the B supply voltage. The circuit of figure 3 shows a 20-megohm resistor in series with the meter. Thus, the meter is capable of reading B plus voltage in position

7, full-scale deflection representing 1000 volts DC. The scale markings on the meter are multiplied by 20 for the equivalent DC voltage.

With the switch in position 8, the meter indicates the relative amount of noise or audio voltage at the receiver output. The output of the receiver is connected to plug terminals 9 and 10, with terminal 10 leading to ground. For monitoring the receiver output, the audio voltage is applied to a speaker mounted in the tester. The speaker voltage is rectified and applied to the positive side of the meter. This becomes a convenient indication when making 20 db quieting tests, because the meter reads the relative amount of voltage, and 20 db represents a voltage ratio of 10 to 1. Meter readings for the different switch positions can be expected to vary from one model of receiver to another.

The recommended deflection for each switch position will be found in the instruction manual of the particular receiver being used. This information should be known when making tests in order to determine whether or not a particular reading can be regarded as normal.

The instruction manual also indicates the specific circuit which is monitored in each switch position. It is, therefore, essential for the serviceman to equip himself with the appropriate instruction manual whenever he uses the test set in conjunction with a receiver.

Transmitter Metering Circuit

In order to monitor transmitter circuits with the test set, the function switch (S1) is set to the METER position, S4 in its XMTR. position, and the meter reversing switch to (-). The circuit is shown in figure 4.

Positions 1, 2, 3, -4, 5 and 6 have the same circuitry and are used in the same way as they were in the receiver positions---to measure negative voltages. Position 1 is used with 450-mc transmitters to measure the amount of RF power in the transmission line (to the antenna). A crystal RF rectifier is incorporated in the transmitter, and the output voltage from this crystal is applied to the meter in position 1.

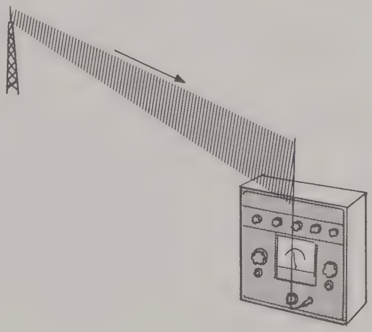
Position 2 is used (only in certain transmitters) to measure the amount of current in the oscillator stage. This makes it possible to adjust the oscillator for maximum activity, where this is necessary for the type of oscillator circuit employed. Positions 3, -4, 5 and 6 measure the grid current in the multiplier stages of the transmitter and they are used in tuning the plate circuits of preceding stages.

The P. A. position measures the plate current of the final amplifier stage of the transmitter. The plate current enters at terminal 8 of P1 and reaches the negative terminal of the meter, the positive side of the meter being returned to terminal 7, which is connected to the high-voltage circuit of the transmitter. Thus, the plate current of the power amplifier stage may be read in the P. A. position. A suitable shunt resistor is incorporated in the transmitter for proper meter indication. The multiplying factor for the meter reading is given in the instruction manual; it varies for transmitters of high and low power output.

Position 7 is used to measure the high voltage of the transmitter. The 20-megohm resistor provides a full-scale deflection of 1000 volts. Thus, the scale reading on the meter is multiplied by 20 to determine the high voltage.

Position 8 indicates the relay voltage which, in mobile applications, is the A supply to the filaments and relays. This voltage, made available at terminal 9 of the meter plug and at terminal 3 of the microphone receptacle, is applied to the meter through the 280 K multiplier resistor. An upward deflection indicates that the input voltage is positive, which means that the vehicle has the negative side of its primary voltage grounded. (If the positive battery terminal is grounded, the meter reverse switch must be used.)

In position 8, the meter becomes a voltmeter with a full-scale deflection of 15 volts. Thus the scale readings must be multiplied by .3 to determine the applied voltage. For example, a reading of 21 on the meter dial corresponds to 6.3 volts. The reading with the switch at position 8 always represents the voltage which is applied before the transmitter is operated. As soon as the transmitter is turned on, the test set indicates zero voltage with the switch at position 8. The line being measured is the "bottom" end of the relay, the control line for turning on the transmitter. In order to energize the transmit relay this line is grounded, either by the switch on the test set or by the one on the microphone.



The Motorola Test Sets May be Used to Measure the Field Strength of a Radiated Wave.

The microphone and audio output voltages are not measured by the P-8501 test set, but these voltages are available at terminal 10 of the meter plug and at the microphone receptacle, respectively. A microphone at the test set can thus be used to modulate the transmitter.

Signal Generator

Figure 5 shows the circuit of the signal generator. This unit consists of a crystal controlled oscillator followed by a multiplier. In addition to serving as a source of voltage at the IF frequencies of any Motorola receiver, the unit can also be used as an RF source for any receiver in the HI or LO bands. All that is required is the proper crystal.

By using the crystal from the transmitter, the combination of oscillator-multiplier provides an output at the channel frequency. Also, by using crystals of 440, 455 and 470 kc (assuming a 455 kc IF with a 15 kc deviation), it is possible to check the response of the discriminator in the receiver.

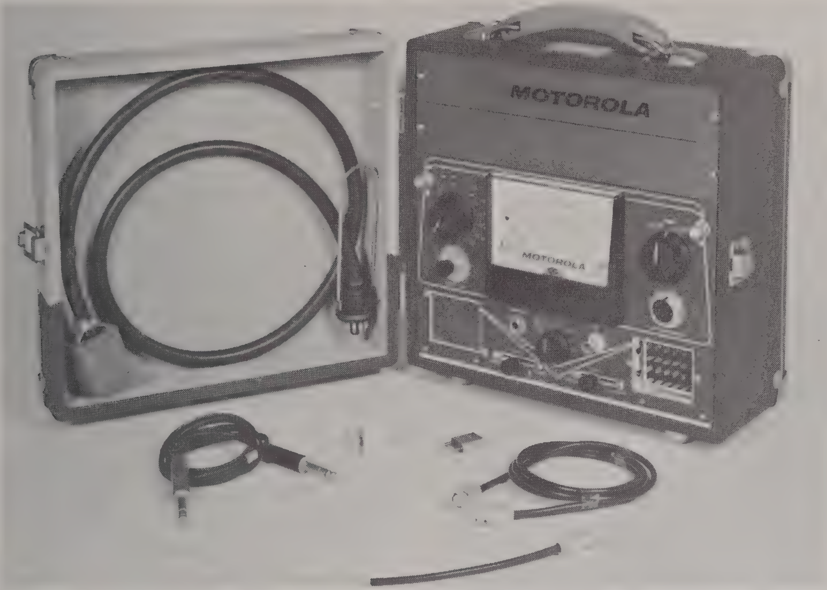
The series mode type of crystal used in some Motorola equipment will not operate properly in the test set. In some cases, in order to use the test set it will be necessary to secure a suitable fundamental mode crystal of the correct frequency.

The relatively high output of the test set, due to its multiplier stage, makes it suitable for alignment of both the RF and the IF sections of the receiver. For RF alignment, the output of the generator, available at the R.F. Out connector (D), is applied directly to the receiver antenna input by means of the cable which is supplied. The output is variable from maximum to zero by means of the attenuator (R9), which controls the screen voltage of both the oscillator and the multiplier.

Two tuning controls, ADJ. and OSC TUNE, are provided in the oscillator-multiplier section. At the low IF frequencies only the ADJ control is used---the other has no effect on either the frequency or the output. The function switch is placed in the GRID CURRENT position and the ADJ control is operated to obtain a maximum meter reading. This provides maximum output at the IF crystal frequency.

To obtain proper results at the higher frequencies, both controls must be used; the ADJ control becomes the means of placing the crystal on the correct frequency, and the OSC. TUNE is used to provide maximum output from the the multiplier. The output is best determined by monitoring the limiter in the receiver; the frequency should be "zeroed" to some discriminator known to be correctly tuned. For higher frequency operation, some small change of frequency may result when the ATTENUATOR or OSC. TUNE controls are varied. The frequency should be rechecked periodically to make sure the oscillator is always at the correct frequency.

The crystal heater obtains its operating voltage from the filament supply of the receiver, through terminal 8 of the meter plug. A resistor in this supply



The TU546 Test Set with Complete Accessories.

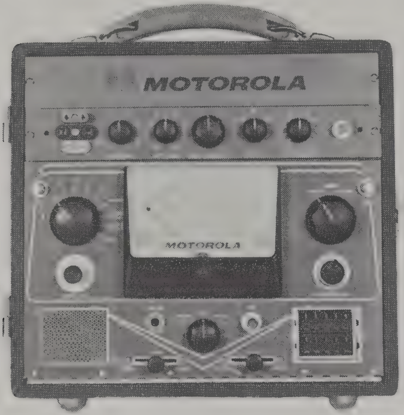
line is switched in or out of the circuit depending upon whether the receiver operates from a 6- or a 12-volt system.

The generator section of the test set operates from self-contained batteries, which supply 1.5 and 67.5 volts, respectively. The ON/OFF switch (S6) is used to connect these batteries to the generator circuits.

(For bench operation, an AC supply such as that shown in figure 6 may be built to save the batteries. The switch allows quick changes between AC and battery operation. The AC supply uses standard parts, all of which may be secured from most electronic supply houses. The components necessary for the construction of this AC supply can easily be mounted on a small chassis which may be installed inside the test set cabinet.)

Microammeter, RF Power and Dummy Load

To use the 0-50 microammeter alone, (1) the function switch is placed in the METER position, (2) position switch S4 is placed in the 0-50 position, and (3) the position switch is placed in the -4 position. The input to the meter is taken from 4 and 11 of the meter plug. The plug fits into an adapter which has connections to terminals 4 and 11, terminal 11 being the ground. This adapter terminates in a jack, which in turn fits into the Motorola dummy antenna, P-7208. The meter circuit, adapter, and dummy antenna load are shown in figure 7.



The TU546P Test Set Includes a Peaking Generator, Located on the Upper Panel.

Figure 7 shows how to determine the transmitter power output from the amount of current indicated on the meter. The power output in terms of current is also a function of the frequency; hence three curves are shown, one for each frequency range. For example; a reading of 30 microamperes in the 152-174 mc range corresponds to a power of 25 watts. Note, also, that the dummy load has a maximum continuous power rating of but 25 watts; for ratings higher than this, operation of the dummy must not exceed 5 seconds duration. If the resistors in the dummy load heat the rectifier crystal (also inside the dummy load), the current will change, resulting in an erroneous reading on the meter.[1]

Field Strength Meter

Figure 8 shows the circuitry of the test set when used as a field strength meter. All that is required is to set the function switch S1 in the FIELD STRENGTH position. This disables all switches and controls except the meter reversing switch. RF energy is introduced into the circuit through the PROBE input connector (C), and the rectifier converts it to an equivalent DC, which is then applied to the meter circuit.

No effort has been made to calibrate the readings on the meter in terms of uv/m (microvolts per meter), due to the several variables involved, which would make such calibration impractical. Moreover, a relative field strength reading is all that is desired by the average serviceman. Although there is no means of calibrating or determining the frequency of the signal being picked up by the meter, it is a means of indicating maximum output from the transmitter antenna. It is also very useful in loading the transmitter for maximum output.[2]

It takes .1 volt DC for full-scale deflection and .002 volt DC for a deflection of one dial division. The meter therefore cannot be used at any great distance from the trans-

---

1. See Test Methods, page 3-23.
2. See Test Methods, pages 1-5, 3-36, and 3-37.

mitter. By providing readings at various distances from the transmitting antenna, however, the field strength meter becomes a valuable instrument for detecting "dead spots."

The TU-546 Test Set

The TU-546 test set, besides performing all the functions of the P-8501 unit, has these additional advantages: No adapters are needed in order to measure the oscillator multipliers in 450-mc receivers; for checking microphone voltage, both the DC supply and the AC output can be measured; the set permits a zero-center discriminator scale reading; it incorporates a transistorized signal generator, having a range from 280 kc to 13 mc and there is provision in the test set for three separate crystals; the internal batteries may be checked by merely placing a switch in the correct position; a fully transistorized AC voltmeter is provided for measuring small AC voltages.

Provision is also made to use the test set with a "peaking generator," which can serve as an RF signal source for receivers up to 960 mc. This peaking generator is an accessory and may be included in the original test set or added afterwards.

Figure 9 is the basic schematic diagram of this test set. A cable shown at the left interconnects the test set with the receiver or transmitter, whichever is being tested. The function switch is normally placed at either RCVR or XMTR, whichever applies. The third position (ACCESS) of this switch disconnects the meter from the internal circuits. The meter movement is then available at the meter jack. In figure 9, the function switch terminals are indicated by the letters X(XMTR), R(RCVR), and A(ACCES).

The meter movement is not fused as in the P-8501 tester; instead, two silicon diodes in parallel with the movement perform the same function and make fuse replacement unnecessary in case of an overload. The meter is connected to the position switch (S1) through the meter reversing switch and the function switch.

Let us now inspect the circuitry of this test set at each position of Switch S1, for both the receiver and the transmitter. We will start with the receiver.

Receiver Measurements

With the set plugged into the receiver and the function switch in RCVR position, the position selector switch may be used to monitor many of the receiver circuits. In positions 1 through 6, the test set is capable of measuring grid currents in the various receiver stages. The negative side of the meter connects through terminals 1 through 6 of switch S1A to the various grid circuits which are to be measured. The positive side of the meter connects to ground in positions 1 through 6 (through the meter reversing switch, the function switch, and switch S1B). In series with this ground path we find a 17.5K resistor, the same as used in the P-8501 tester. This ground lead completes its path to the receiver through terminal 11 of the plug.

Although position 4 has the same general circuitry as positions 1, 2, 3, 5 and 6, this position is used to measure the secondary of the discriminator, which is a "zero" reading. To facilitate the meter deflection to both sides of zero, a special circuit is added to switch position 4 which places the normal position of the needle at the center of the meter scale. Special scale markings have a zero-center scale reading with graduations from zero in both directions.

Zero-center needle deflection in position 4 is obtained by means of a separate battery source and series connected resistors, which limit the current to 25 microamps (center-scale deflection). This circuit is shown to the right of the meter in figure 9. Switch S1D completes this circuit when the switch is in position 4, but the function switch must also be in its RCVR position. The 1.5-volt battery is now in series with a fixed resistor and a variable resistor, and the needle can be brought to exact center-scale deflection by adjusting the variable resistor. In any other position of the switch, the zero-center circuit is inoperative.

Positions 7 and 8 of the meter, (labeled PA and PO), are not normally used for receiver measurements except in the case of 450-mc receivers. With these receivers, the multiplier switch is placed in the MULT position, the meter now indicating the grid current for the circuits (the oscillator multipliers) terminating at plug terminals 7 and 8. By means of a spring-return arrangement, the switch will never be left in the MULT position except when making this specific measurement. As soon as the readings are completed the switch is returned to the 2 VAC position.

Position 11 provides for audio output measurements. The receiver audio terminates at plug connection 9, and with the function switch at RCVR, the audio is applied to the input of the AC voltmeter section. In parallel with this input (when the function switch is at RCVR), we find the speaker switch. This switch terminates the audio line into either a 3-ohm dummy load, a 3-ohm speaker, or a 27-ohm resistor in series with the speaker (which is effectively an "open" to the audio line).

The two stage amplifier (transistorized) terminates in a rectifier circuit in order to produce a reading on the meter. In position 11 the meter is connected across the ends of this rectifier circuit. With the AC Meter switch in the 2-volt position, a 2-volt input causes full-scale deflection. In the 0.2-V position, a 0.2-volt

AC input will cause full-scale deflection. Thus, the meter indicates the output voltage from the receiver.

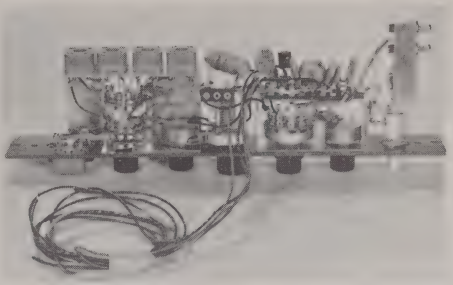
Transmitter Readings

When the test set is connected to the transmitter and the function switch placed in the XMTR position, a microphone may be plugged into the microphone receptacle, and either the mike switch or the switch on the test set may be used to place the transmitter in operation. The following readings may then be taken:

In positions 1 through 6 the meter indicates grid current, the same as for the receiver. Terminals 1 through 6 of the plug terminate at terminals 1 through 6 of switch S1A and, the circuit is completed through the meter to ground with only the 17.5K resistor in series.

Position 8, which is marked PO, is used only for determining the power output of 450-mc transmitters. A portion of the output power from the final tank is coupled through a rectifier to terminal 1 of the interconnecting plugs. Terminals 1 and 8 of switch S1A are interconnected through the function switch and the multiplier switch. So power output measurements of 450-mc transmitters can be made at either position. Position 8 is handier, however, since it is located next to position 7 (PA).

Position 7 is used to determine the plate current of the final stage. The circuit for this measurement is identical to that of the P-8501 test set. The meter and its series-connected 17.5K resistor are connected in parallel with the meter shunt resistor (in the plate supply lead to the final amplifier). The B supply lead and the plate side of the resistor are connected to plug terminals 7 and 8, respectively. The exact amount of plate current (the multiplication factor of the meter) is determined by the resistance of the shunt in the transmitter; the instruction manual must be consulted for the exact value of plate current for each transmitter.



Here We See the Transistorized Peaking Generator Which is a Part of the TU546P Test Set.

In position 9 the meter indicates the plate supply voltage applied to the final stage of the transmitter. B plus is available at pin 7 of the plug connector and a 20-megohm resistor is connected in series with the meter to allow a 1000-volt DC full scale reading. This resistor is located between the B plus input at terminal 7 and terminal 9 of S1B. The circuit through the meter is completed to ground through terminal 9 of switch S1A.

In position 10 the meter indicates the A supply voltage applied to the relays. If the relays operate from a battery supply, this reading represents the battery voltage. Terminal 10 of S1A is grounded and the positive side of the meter connects to terminal 10 of S1B. By means of 300K series-connected resistor at this terminal, the meter will read 15 volts, full scale, useful for both 6- and 12-volt systems. This A voltage is available at terminal 9 of the plug connector but the circuit to the meter is completed only when the function switch is in the XMTR position (dotted lines).

In position 11 the meter indicates the audio output from the microphone. The audio component of the mike voltage (available at terminal 1 of the mike connector) is applied to the input of the amplifier and the meter is connected across the output of the amplifier, the circuit being the same as for the audio output of the receiver. With the function switch in the XMTR position, however, the speaker switch is no longer in parallel with the amplifier input. The microphone may be that of the transmitter or it may be one plugged into the test set. In either case, normal voice modulation causes a reading of about 0.25 volt on the meter, assuming a higher voltage output type of microphone. For lower voltage microphones the reading will average 0.18 volt. For this test the transmitter must be placed in operation or there will be no microphone DC supply voltage.

Position 12 of the switch is used to measure the microphone DC supply. The path between terminal 10 of the plug connector and terminal 1 of the microphone receptacle is completed through a 600 K resistor to terminal 12 of S1A, through the meter, and to ground at terminal 12 of switch S1B. The 600 K resistor is used for a full-scale reading of 30 volts, which is adequate for the microphone supply.

Position 13 is used to obtain an immediate check on the condition of the internal battery of the test set.

Position 14 is used to measure the relative amount of RF output of the internal crystal oscillator. A small coupling capacitor feeds the oscillator output to a voltage doubling rectifier circuit and results in a relative reading on the meter. Position 14 is also used when the test set operates as a field strength meter. The output of the pick-up antenna is connected to the RF connector. With the switch in position 14, the meter indicates the RF level.

The Crystal Oscillator

The transistorized crystal-controlled oscillator, shown at the lower right of figure 9, operates at any frequency between 280 kc and 13 mc. The principal purpose of this oscillator section is to provide a signal at the various IF frequencies for receiver alignment. Three internal crystal sockets are provided, selection being made by means of the switch on the front panel. The oscillator uses "AQL" type crystals for frequencies up to 800 kc and "ANL" type crystals above 800 kc. These are both anti-resonant crystals (appearing as a parallel tuned circuit to the oscillator).

Position 14 is used for automatically monitoring the output of the oscillator, giving a relative indication of crystal activity. This is particularly useful in checking the activity of unknown crystals. Due to the differences of frequency ranges and cuts of crystals, however, and due to the limited supply voltage to the oscillator, the failure of a crystal to operate is no proof that the crystal is defective.

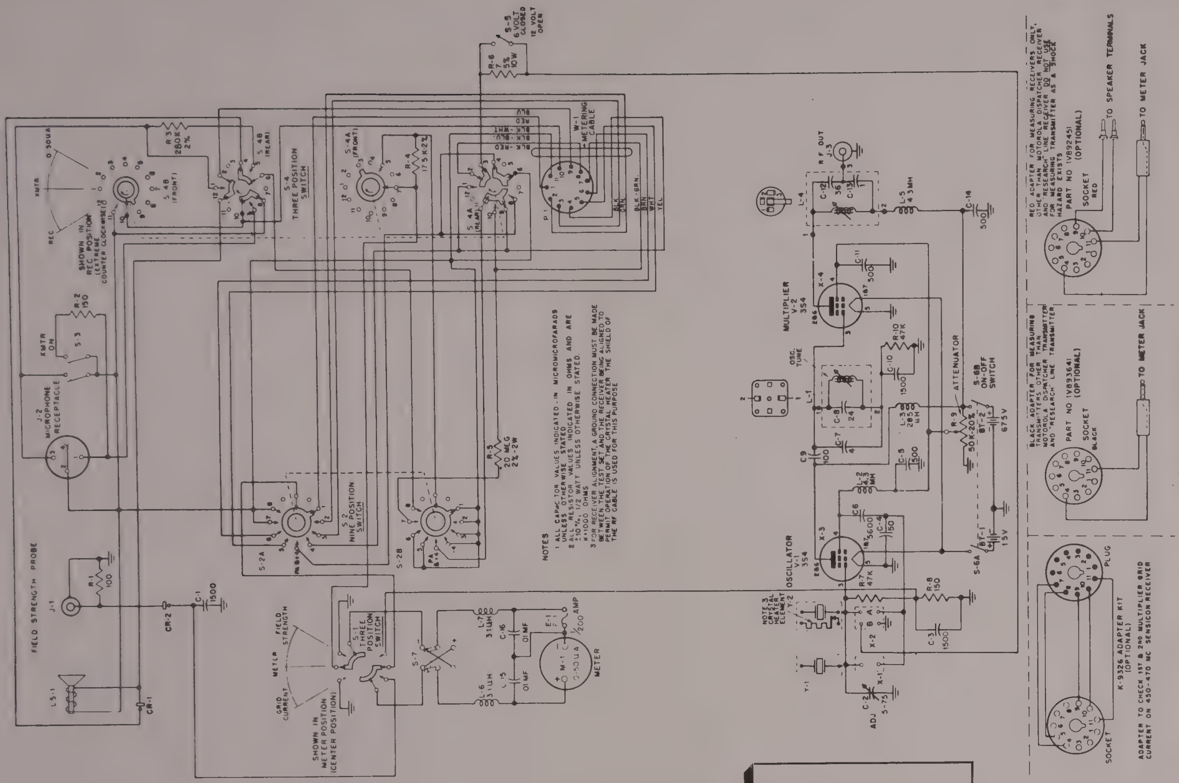
Peaking Generator

The transistorized RF peaking generator provides a high order of harmonics of the fundamental 6-10 mc crystal oscillator frequency, and serves as a signal source for the low band (25-54 mc), the high band (144-174 mc), the 450-470 mc band and the 890-960 mc band. If not originally included with the test set, this generator may be added later as an accessory item.

The peaking generator makes use of an "AUL," anti-resonant type of crystal. In some instances the crystal from the transmitter oscillator will operate satisfactorily; if not, crystals may be purchased at low cost for any channel of operation. A frequency adjustment is provided for placing the generator on exact channel frequency, and an output attenuator provides the desired amount of RF signal for the receiver.

STUDENT NOTES

STUDENT NOTES



NOTES

1 ALL CAPACITOR VALUES INDICATED IN MICROMICROFARADS UNLESS OTHERWISE STATED

2 ALL RESISTOR VALUES INDICATED IN OHMS AND ARE ±10%, 1/2 WATT UNLESS OTHERWISE STATED. K=1000 OHMS

3 FOR RECEIVER ALIGNMENT, A GROUND CONNECTION MUST BE MADE BETWEEN THE TEST SET AND THE RECEIVER BEING ALIGNED TO PERMIT OPERATION OF THE CRYSTAL HEATER THE SHIELD OF THE RF CABLE IS USED FOR THIS PURPOSE

RED ADAPTER FOR MEASURING RECEIVERS ONLY, OTHER THAN MOTOROLA DISPATCHER RECEIVER AND "RESEARCH" LINE RECEIVER DO NOT USE FOR MEASURING TRANSMITTER AS A SHOCK HAZARD EXISTS
PART NO 1V892451
(OPTIONAL)

BLACK ADAPTER FOR MEASURING TRANSMITTERS OTHER THAN MOTOROLA DISPATCHER TRANSMITTER AND "RESEARCH" LINE TRANSMITTER
PART NO 1V893641
(OPTIONAL)

K-9326 ADAPTER KIT
(OPTIONAL)
ADAPTER TO CHECK 1ST & 2ND MULTIPLIER GRID CURRENT ON 450-470 MC SENSICON RECEIVER

FIGURE 2

FIGURE 1
is on the
back of this page

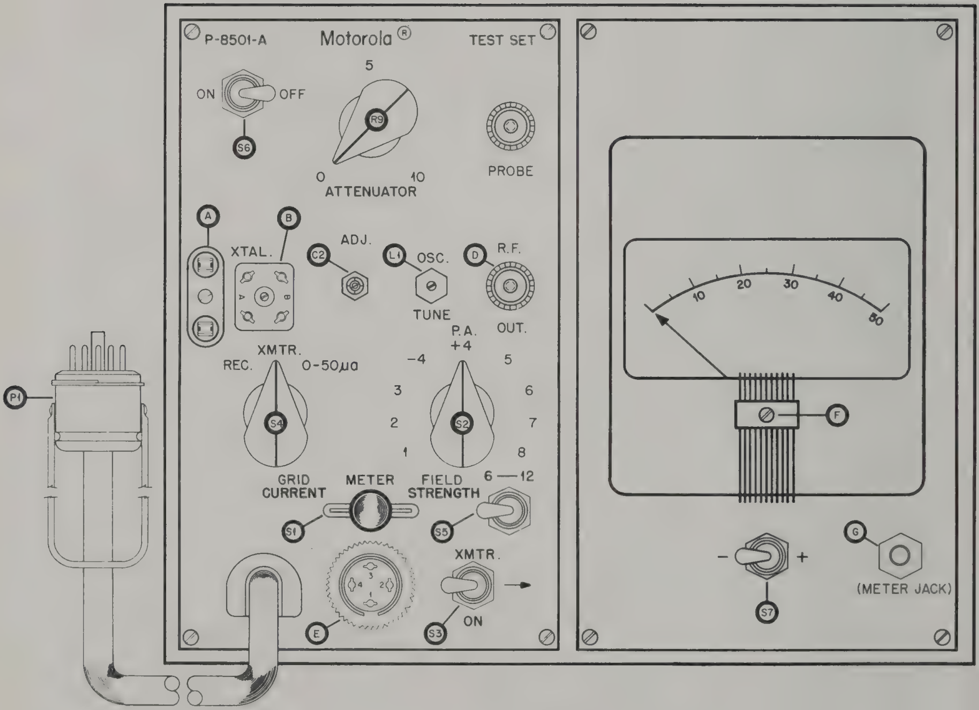
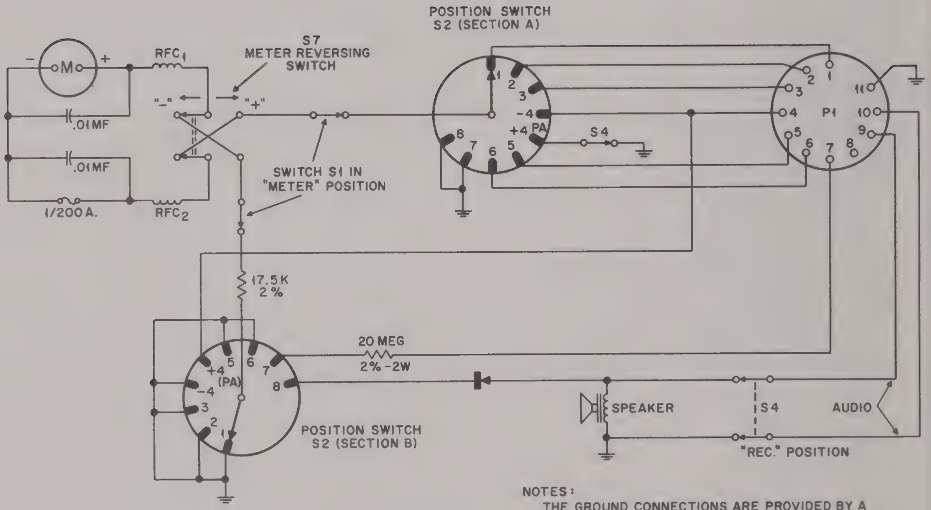

P-8501-A
Motorola®
TEST SET
5
ON
OFF
S6
R9
0
10
ATTENUATOR
PROBE
A
B
XTAL.
ADJ.
C2
L1
OSC.
D
R.F.
TUNE
OUT.
P1
XMTR.
REC.
0-50μa
S4
-4
P.A.
+4
5
3
6
2
S2
7
1
8
GRID
CURRENT
METER
FIELD
STRENGTH
6 — 12
S1
S5
E
XMTR.
S3
ON
10
20
30
40
50
F
-
+
S7
G
(METER JACK)

FIGURE 1

STUDENT NOTES

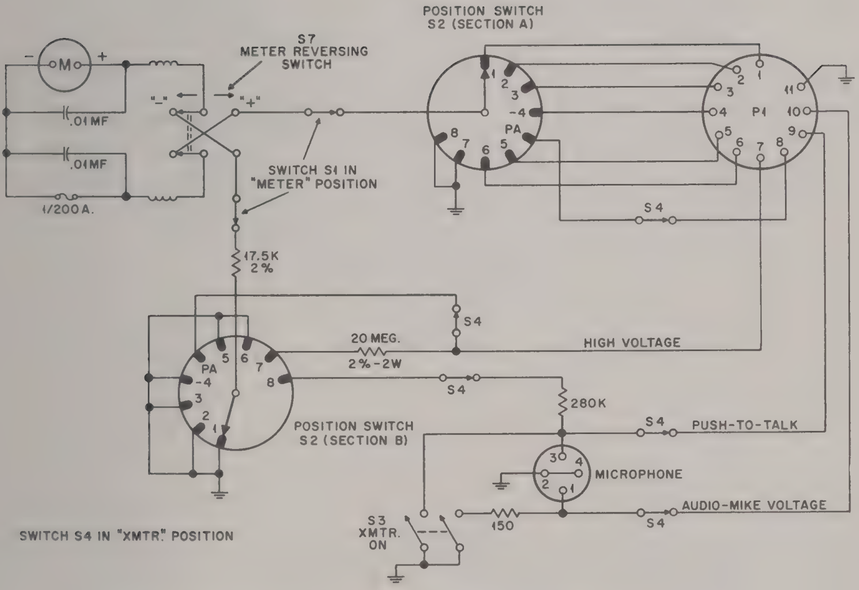
STUDENT NOTES

STUDENT NOTES

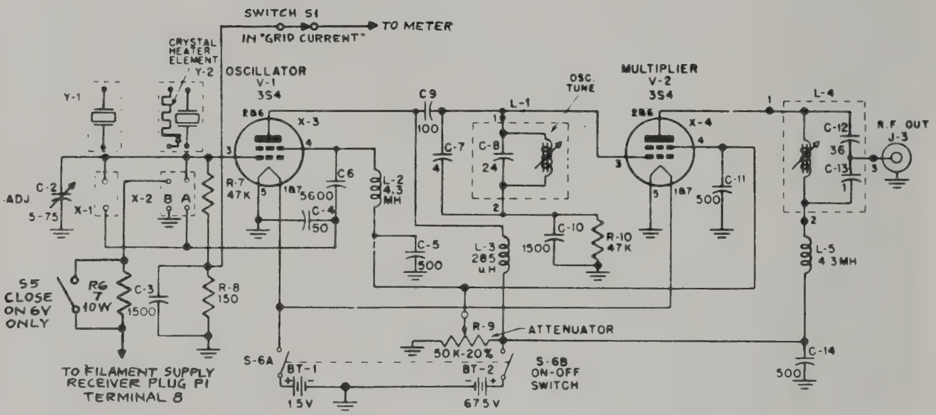


NOTES:
THE GROUND CONNECTIONS ARE PROVIDED BY A COMMON CONNECTION TO TERMINAL 11 OF P1, WHICH IS GROUNDED THROUGH THE RECEIVER CHASSIS.
SWITCH S4 IN "REC." POSITION.

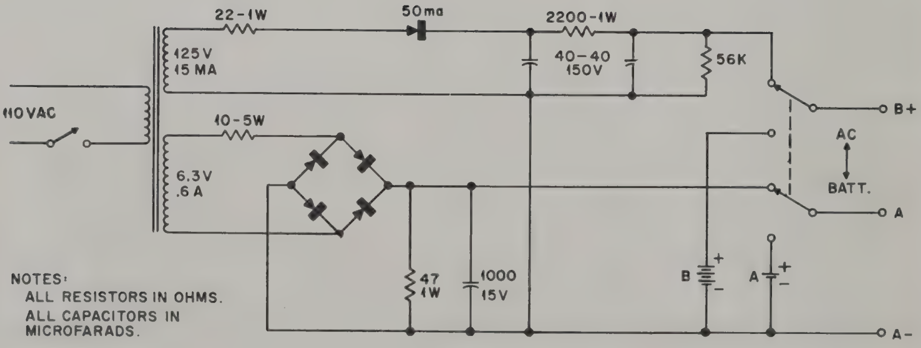
P-8501-B TEST SET--RECEIVER METERING CIRCUIT
FIGURE 3



P-8501-B TEST SET -- SIMPLIFIED DIAGRAM OF TRANSMITTER METERING CIRCUIT
FIGURE 4



TEST OSCILLATOR OF
MOTOROLA P-8501-B
TEST SET
FIGURE 5

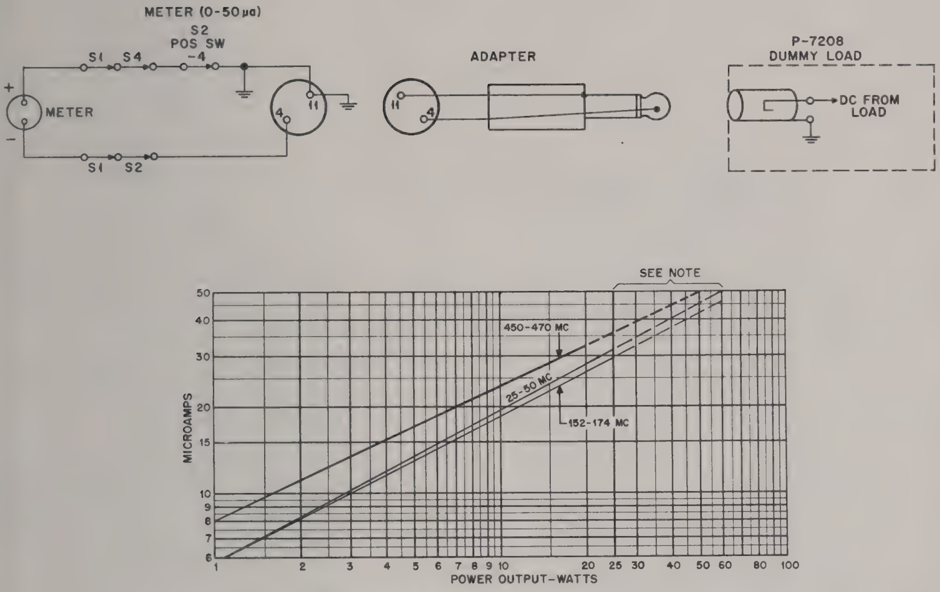


NOTES:
ALL RESISTORS IN OHMS.
ALL CAPACITORS IN MICROFARADS.

AC POWER SUPPLY
FIGURE 6

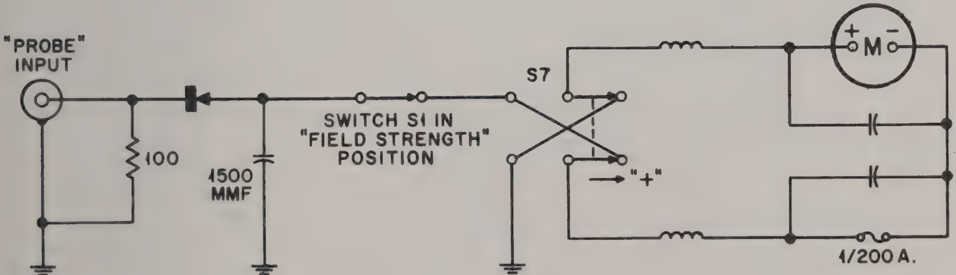
STUDENT NOTES

STUDENT NOTES



NOTE:
LOAD RATED AT 25 WATTS CONTINUOUS DUTY AND
UP TO 60 WATTS FOR SHORT PERIODS (5 SECS. MAX.).

FIGURE 7



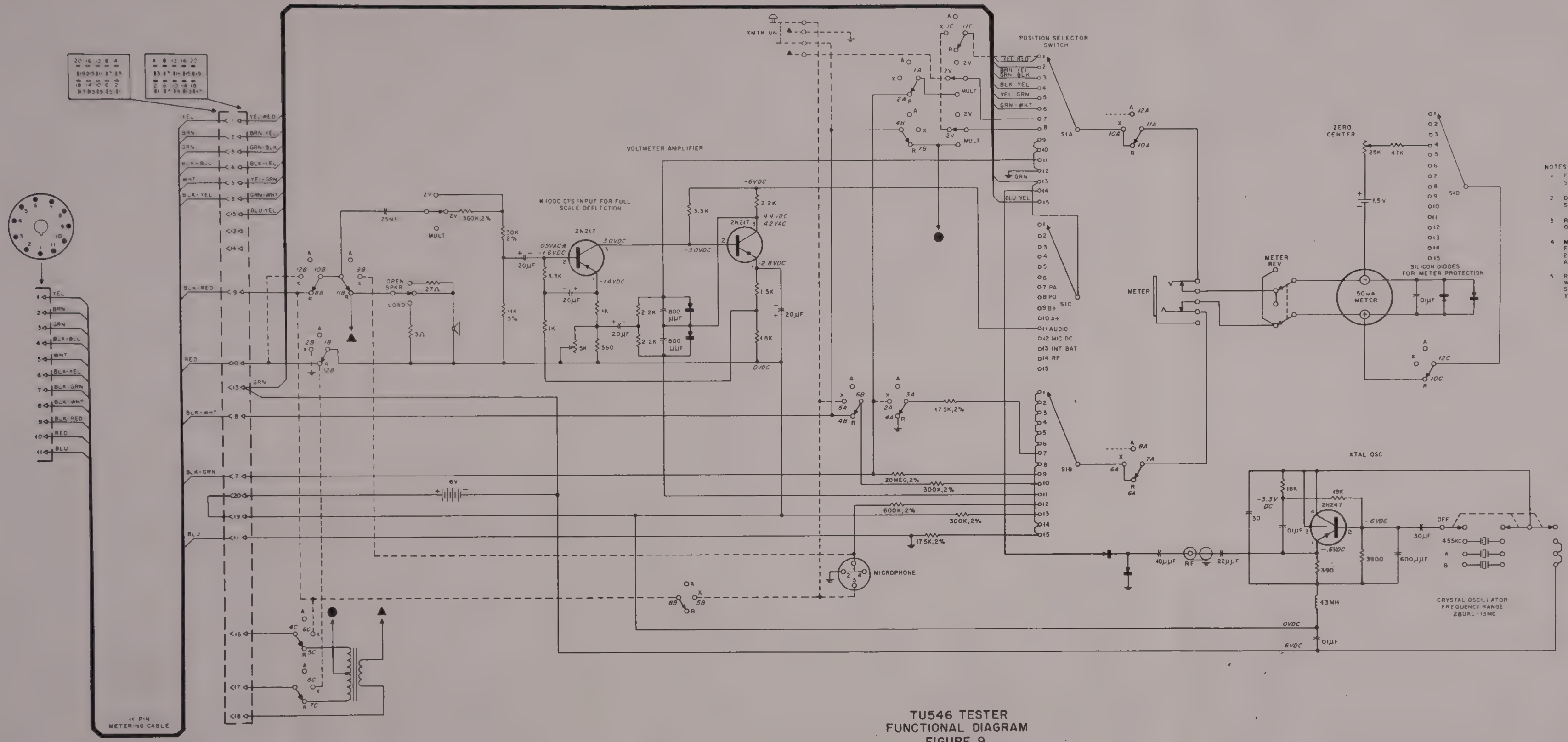
NOTES:
SWITCH S1 IN "FIELD STRENGTH" POSITION
METER REVERSING SWITCH S7 IN "+" POSITION

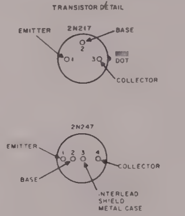
"FIELD STRENGTH" CIRCUIT OF P-8501-B MOTOROLA TEST SET

FIGURE 8

STUDENT NOTES

STUDENT NOTES




TRANSISTOR DÉTAIL

NOTES

1. FUNCTION SELECTOR SWITCH(RCVR XMTR ACESS) SHOWN IN RCVR POSITION
2. DASHED LINES INDICATE CIRCUITRY WHEN FUNCTION SELECTOR SWITCH IS IN XMTR POSITION
3. RF OSCILLATOR VOLTAGES TAKEN WITH OSCILLATOR OPERATING
4. MEASUREMENTS OF AUDIO VOLTMETER TAKEN WITH FUNCTION SELECTOR SWITCH IN XMTR POSITION, 2.0 VAC APPLIED TO PIN 1 OF MICROPHONE RECEPTACLE AND SWITCH 1 IN POSITION 11
5. REFERENCE NUMBERS ON R-X-A SWITCH REFER TO WAFER SWITCH SECTIONS OF THE FUNCTION SELECTOR SWITCH ON CIRCUIT DIAGRAM 63E849846 6A REFERS TO WAFER SECTION S2A, TERMINAL 6

TU546 TESTER
FUNCTIONAL DIAGRAM
FIGURE 9

national
MOTOROLA
RADIO COMMUNICATIONS
service

A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON MA-4
MAINTENANCE

Trouble Shooting In General

MOTOROLA TRAINING INSTITUTE

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Trouble Shooting In General

—one of a series of lessons on two-way FM communications—

MOTOROLA TRAINING INSTITUTE
4501 W. AUGUSTA BLVD., CHICAGO 51, ILLINOIS
APPROVED BY THE STATE OF ILLINOIS
DEPT. OF REGISTRATION AND EDUCATION

PREFACE

This is one lesson of a complete Motorola Home-Study Course which presents to the Service Technician both the principles of operation and the maintenance of two-way FM radio systems. The program covers mobile, portable and base station equipment, including the latest transistorized units.

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GENERAL TROUBLE SHOOTING

LESSON MA-4

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NOTICE

Diagrams and figures referenced in text are "fold-outs" in back of each lesson, for use while studying. The Examinations are also there.

In the event of disaster, radio invariably remains as a reliable method of communications. Civil Defense organizations throughout the country have established extensive two-way radio networks in preparation for all emergencies.

GENERAL TROUBLE SHOOTING

Lesson MA-4

Introduction

It should be remembered that trouble shooting is but one phase of equipment maintenance. Trouble shooting assumes that some piece of equipment in the communications system has already become faulty so that normal contact is not possible or is not reliable.

In addition to trouble shooting, there must be preventive maintenance of electronic equipment. This includes general inspection, equipment tests, and certain required frequency and deviation checks.

In this assignment we will be concerned only with that phase of maintenance which might be classified as "emergency" maintenance, wherein a system or some portion of a system is not functioning properly and must be placed in operation "as soon as possible." We will be concerned here with general procedures only; specific instructions for trouble shooting the receiver and transmitter will be given in the assignments which follow.

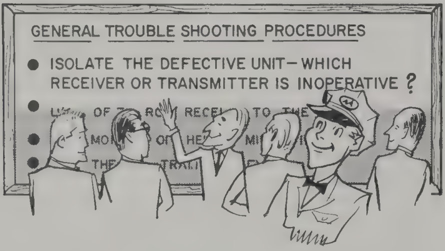
General Procedure

The complete trouble shooting procedure may involve as many as six steps to make certain that proper corrective measures have been taken, and that the system has been restored to normal operation. In certain instances, the nature of the trouble may simplify these steps or even eliminate one or more of them. This will be determined by the circumstances of each situation.

The first step is to determine where the fault lies. For example, a police squad car pulls up to your shop and the operator complains that his rig is dead. A check of the system may show that the transmitter is okay (the base station hears the squad car signals). However, the squad car operator does not hear the base. This indicates either (1) a faulty receiver in the squad car, or (2) a faulty transmitter at the base. By opening the squelch, a quick check may be made on the receiver. If no noise is heard, the fault is probably in the receiver; if normal noise is heard, the trouble could still be in the receiver, but it might also be at the base transmitter. If there are other squad cars in the system, a check on the operation between the base and one of the other cars will immediately isolate the trouble.

The important fact to be recognized is that the trouble must be definitely isolated to some particular unit of the system before any one unit is subjected to a detailed analysis.

Assume that the receiver is at fault. Without removing the receiver from its case, a Motorola test set may be used to make a general check of the unit. Again it is possible that the trouble might not be in the receiver, but in the power supply. In some models, the transmitter and receiver operate from different sections of the supply, or even from different supplies.


GENERAL TROUBLE SHOOTING PROCEDURES
ISOLATE THE DEFECTIVE UNIT—WHICH RECEIVER OR TRANSMITTER IS INOPERATIVE ?

Make Complete Checks on the Operation of the Entire System.

After the fault is definitely isolated to a particular unit, the next problem is to determine which stage or section within the unit is at fault.

The next step is to find the defective component (or perhaps the control or circuit that is misadjusted). This may consist only in replacing one or more tubes, or it might require the removal of the chassis for further inspection on the test bench. In the latter case, additional test instruments (voltmeter, ohmmeter, signal generator) are usually required in order to determine the exact trouble.

After a fault has been discovered, determine the proper corrective measures. If a poor connection or broken wire is found, the procedure is obvious enough. Where a component is defective, the problem is one of correct replacement. More will be said about this later.

After the trouble is corrected, the individual unit is checked for operation (correct meter readings, sensitivity, power output, etc.). It is then placed in the car and its operation with the rest of the system is verified.

Isolating the Defective Unit

In any trouble shooting procedure, considerable time will be saved by quickly isolating the defective unit. Knowledge of the normal operation of the entire system will furnish the technician with a definite idea of the possible cause of trouble. Thus, in order to provide intelligent service, the technician must be familiar with the operational characteristics of the system.

In a typical two-way communications system the base station, as the dispatcher, controls the traffic of the mobile units. In order to have communication between vehicles, the same frequency is used for all the transmitters and receivers in the system. The mobile vehicles, let us assume, do not normally operate in extreme fringe areas but are close to the base station---the signal is thus normally stronger than necessary, and there is plenty of system "reserve."

These vehicles, however, may occasionally enter areas where communications from car-to-car is not 100% reliable. This may be due to foliage, high buildings, or other obstacles. Let us further assume that the serviceman makes a routine check each month of each transmitter and receiver, and that he regularly corrects all malfunctions such as low power output in the transmitters or poor sensitivity in the receivers.

Let us now suppose that car No. 1 comes to your shop and the operator complains that, although he is able to hear the base station, he cannot "talk back." This situation is the same everywhere, even in good areas, which eliminates the possibility that the car might have been in a "dead spot." Investigation shows that the base station has normal in-and-out traffic with the other mobiles; hence, the trouble is not in the base station receiver. The fault seems to be with the mobile transmitter in car No. 1. This is confirmed by the operator of car No. 2, who states that once, when car No. 2 was about a block away from car No. 1, the operator of car No. 2 heard car No. 1 trying to talk to the base. As soon as car No. 2 was farther away from car No. 1, the signal died out. We can be reasonably sure now that the output of the transmitter is very low. The Motorola test set may be used for further checks on the operation of the unit.

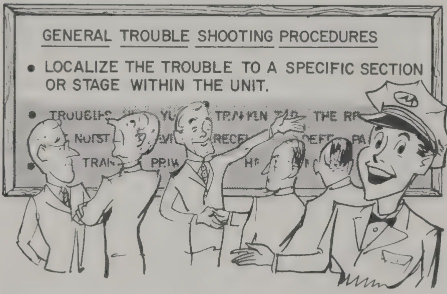
As another example, let us assume the same general complaint from car No. 1---no contact from the car to the base. The other cars report, however, that they hear car No. 1. Moreover, the other cars have been experiencing the same trouble---they can't talk back to the base. The trouble now seems to be associated with the base station receiver.

In both these examples the basic complaint was the same --- no contact from car No. 1 to the base. In the first instance, additional information indicated that the trouble would be found in the transmitter at car No. 1. In the second instance, however, the trouble seemed to be at the base receiver. This illustrates the importance of making a complete check of the operation of the entire system before deciding that any particular unit is defective.

The solution of many problems is not always so obvious. It is then necessary to make further checks before the trouble can be isolated to a particular unit. Or, the trouble may be due to poor operation of several units---the transmitter power may be weak and at the same time the sensitivity of one of the receivers may be poor.

General Check of Individual Units

Where the symptoms are inconclusive and the fault cannot be directly assigned to one unit within the system, it may be necessary to make an over-all check of all the suspected units.


GENERAL TROUBLE SHOOTING PROCEDURES
• LOCALIZE THE TROUBLE TO A SPECIFIC SECTION OR STAGE WITHIN THE UNIT.

The Test Set is Helpful in Localizing a Fault Within the Unit.

Where a system has some reserve, the output of a transmitter may gradually decrease without causing any particular trouble. This reserve is desirable, for it obviates the necessity of servicing the system every time one unit becomes a little weak. Where the output of a base transmitter has decreased and, at the same time, the sensitivity of one or more mobile receivers has also decreased, normal contact may no longer be possible. In such cases, the obvious answer is to restore all units to their normal operating condition. The transmitter as well as the receiver (s) should be returned to normal power output and full sensitivity, respectively.

For trouble shooting the transmitter, a Motorola test set and wattmeter are among the most useful test instruments. By indicating the power output, the wattmeter gives an immediate check of the over-all operation. If the output is low, the test set will indicate which stage is not up to par, and further checks may then be made. If the power output seems to be normal, the operating frequency may be checked, provided another receiver in the system can be monitored. With the switch on the Motorola test set placed in position 4 of the receiver, the reading will then indicate whether or not the incoming signal is "on channel." This reading is normally zero. If the transmitter is off frequency, a frequency meter should be used to correct the condition.

The power output of the transmitter may be measured by means of a thru-line wattmeter, either with a dummy load or with the antenna system connected. This unit shows the amount of power traveling each way in the transmission line and gives a good indication of how much of the power going to the antenna is actually being radiated into space. Unless the reflected power is very low in comparison to the forward power, the poor operation of a system may be attributed to the antenna or transmission line.

In order to make a quick check of the receiver, it is important to have a Motorola test set and an RF source of the correct frequency. Using this test set, meter reading at positions 1 and 2 will indicate the operation of the front-end of the receiver; position 6 (in most receivers) can be used to check oscillator activity. These readings are taken with no signal applied. With a signal of the correct frequency applied, the discriminator secondary (position 4) should read zero. These readings, together with the noise heard when the receiver squelch is open, can be used as a general check of receiver operation. If the operation seems to be normal, a signal generator can be used to determine the receiver sensitivity. The generator used for this purpose must have an accurate calibration of its output voltage.

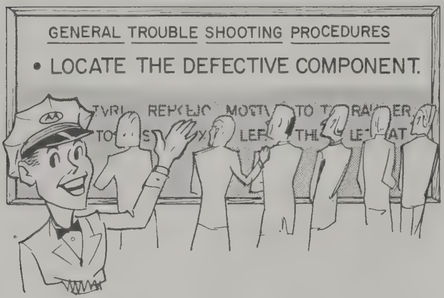
The output of the transmitter power supply can be measured by means of the test set. Low supply voltages can well be the cause of low power output from the transmitter or low sensitivity at the receiver. In addition, the possibility of a weak battery in the vehicle must also be considered, for this will result in a low supply voltage both to the receiver and to the transmitter. Power supplies should never be overlooked when trouble shooting individual units.

Locating The Defective Part

Having determined the defective portion of the unit, the technician is now faced with the problem of finding which particular component within the complete unit is the source of trouble. He knows the particular stage or section which is at fault--he must now determine which component is defective. The experienced serviceman knows that most troubles are due to defective tubes, so his first procedure is to substitute new tubes for those which might be causing trouble. At the same time, the test set is plugged into the unit and the effect of tube substitution upon the various readings is noted. If a new tube does not restore normal operation, the next step will vary according to the nature of the fault and according to whether the unit is a receiver or a transmitter.

When working on a transmitter, the serviceman starts with the oscillator and proceeds through each successive stage until the exact location of the trouble is determined. Each stage is checked by means of the nearest meter position. Watching these readings, he adjusts each circuit until the proper peak indication is obtained when tuned through resonance; it may also be necessary to check the neutralization and the coupling in some units. This procedure should definitely pinpoint the defective stage.

If the tube is good and the tuned circuits seem to show normal peaks, it may be necessary to take voltage and resistance readings. As a final step, the serviceman should try substituting parts in the suspected stage. This procedure is not infallible, of course, and the test may prove inconclusive, but by following a logical procedure the defective part will eventually be located.


GENERAL TROUBLE SHOOTING PROCEDURES
• LOCATE THE DEFECTIVE COMPONENT.

Voltage and Resistance Tests Usually Provide this Answer.

When working on a receiver, the procedure may be somewhat different, because there is no input to the receiver except from a transmitter or signal generator. Again, the procedure may vary according to the symptoms found in the preliminary checks. A signal generator can be used for stage-by-stage sensitivity checks and this is one method of definitely isolating the fault to a particular stage. These checks are made by adjusting the tuned circuits to resonance and noting the peak indications. When the trouble is isolated to a particular section of the receiver but not to a specific stage, it may become necessary to take voltage and resistance readings. The exact procedure will be governed by the symptoms.

Where the antenna system is the source of trouble, the problem may be simplified because of the limited number of parts. If the antenna is on a high tower, however, the service procedure may be difficult. The previously mentioned thru-line wattmeter may prove a very helpful instrument for determining whether the trouble is in the antenna or in the transmission line. A comparison of the forward and reflected power measured both at the beginning and at the end of the transmission line (if convenient) will usually show which is at fault, the antenna or the line.

Parts Replacement

We have now reached the point where the serviceman must replace a defective part with a good one. There are a number of components within the equipment with ratings which are not considered critical (a bypass capacitor can often be made larger without changing the operation of the unit). In most cases, however, the serviceman must observe the exact value and rating of the part being replaced. Wherever possible, the new part should be identical to the old one, and secured from the manufacturer of the original part. If this is impossible, the replacement should at least have an identical rating. For example, the wattage rating of a resistor must be the same or higher than that of the original. If the part is a capacitor, the voltage rating must be the same or higher. There are many other important factors in connection with replacement parts besides wattage and breakdown voltage. If a resistor has a 5% tolerance, for example, the new unit should also be within 5% of the indicated resistance. If the defective capacitor has certain ratings with regard to temperature and capacitance, the replacement must have the same ratings.

It is important when making replacements to position the new part in the exact same location as the original, and to be careful that the wiring is not disturbed. This is most important, of course, in the front end of the receiver. A coupling capacitor in the RF stage to the mixer, for example, may cause oscillation unless it is positioned close to the chassis.

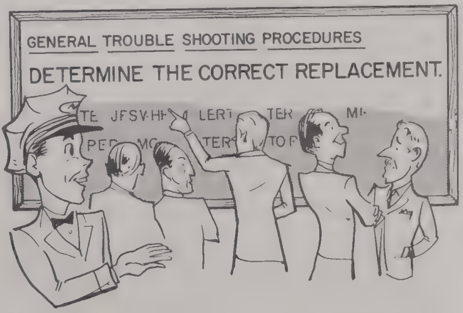
Before replacing a defective part, the actual cause of the defect should itself be removed. In many instances a bypass capacitor may have shorted, causing a resistor to burn out. The short in the capacitor may easily go unnoticed while the burned out resistor is found at once by visual inspection. If the shorted capacitor is left in the chassis when the resistor is replaced, the new resistor will also burn out.

Recheck and System Testing

After a unit has been repaired, its operation should be checked and, if possible, it should also be bench-tested for some period of time to make sure that it will continue to operate.

After the unit has been thus tested for normal operation, it can be installed in the vehicle and a complete check made on its operation within the system. It is most important that the receiver or transmitter be "netted" with the rest of the system.

This concludes our discussion of general trouble shooting procedures.[1] The use of most trouble-shooting instruments can be explained more specifically, of course, when included in a more complete analysis of the receiver or transmitter. The following assignments on receiver and transmitter servicing will contain this information. The voltmeter and ohmmeter can be discussed at this time, however, and the remainder of the assignment will be devoted to explaining the use of these instruments. First, however, it is well to point out that we need not know the internal circuitry of either of these instruments. It is far more important to know how to use them intelligently.


GENERAL TROUBLE SHOOTING PROCEDURES
DETERMINE THE CORRECT REPLACEMENT.

Get Replacement Parts From the Manufacturer Whenever Possible.

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[1] See Test Methods, section 1, pages 1-2 and section 3, pages 1-5.

Using the Voltmeter

The voltmeter is an arrangement of resistors and a meter (sometimes vacuum tube controlled for greater sensitivity) which indicates the voltage or difference of potential existing between two points of a circuit. Because the voltmeter does not have an internal source of voltage, the equipment being measured must be "ON" when voltage tests are being made. The meter is connected in parallel with the particular portion of the circuit being tested. Thus, the circuit being measured is not broken, nor is anything disconnected for this test.

It must be remembered that the meter is a resistor as far as the circuit being tested is concerned, and when the meter is connected we are actually placing a resistor across the circuit. In most circuits, the high resistance of the VTVM (vacuum-tube voltmeter) does not noticeably affect the circuit operation. In certain circuits, however, the presence of the meter does change the circuit operation and it is not impossible for a "dead" receiver to start operating when the meter is connected for a voltage check! We are now ready to look further into the use of the voltmeter in testing procedures.

Figure 1 shows the circuit of the last IF amplifier stage and the first limiter stage in a typical communications receiver. We are assuming that the signal is lost at the grid of the limiter - - -there is no meter indication at this grid. Tube replacements have failed to restore operation, and the receiver has been brought to the test bench for repair.

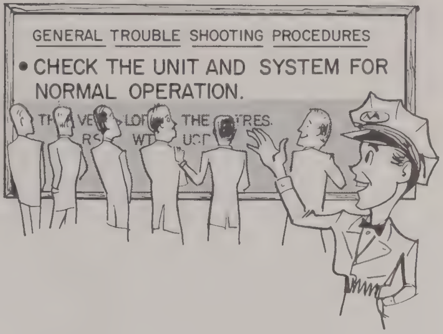
The voltmeter tells us that the B supply voltage, between B plus and ground is normal. A further check at points C and D, however, shows no voltage present. A check at point E is also zero with respect to ground. The logical conclusion is that resistor R3 is open. The resistor may be replaced, of course, but additional tests are necessary to make sure that some other defect in the circuit is not causing the resistor to burn out. Suppose that when the resistor is replaced and the power turned on, the replacement unit also quickly overheats.

Several procedures are now possible. With the power off, an ohmmeter can be connected between point E and ground. Zero resistance would mean that C4 is probably shorted, or there could be a short between plate and cathode of the tube. (The tube can be removed to determine if it is defective.) A wire may have become shorted by rubbing against some sharp point, or a tie-point may be shorted in some manner. These shorts can be located by a visual inspection of the parts and wiring.

If operation seems to be normal after the resistor is replaced and there seems to be no reason for the burning out, we must look elsewhere for a logical explanation. The tube might have been intermittently shorted; this could burn out a resistor. If this seems to be the only explanation, it might be well to replace the tube, for there is a good chance that the tube may short again in the future.

While making the original voltage checks on the circuit of figure 1, if the voltmeter had been placed across the terminals of resistor R3, there is a good chance that the receiver would have started to operate, although the output would have been below normal. This would be because the resistance of the meter, being substituted for R3, completed the path from B plus to the plate and screen circuits of the tube. Even though the resistance may be many times higher than the normal circuit value, the circuit will still operate sufficiently to allow some signal to get through the receiver. When nonelectronic meters having low sensitivity are used, the low-voltage scale may actually restore normal operation when the meter is placed across the resistor terminals.

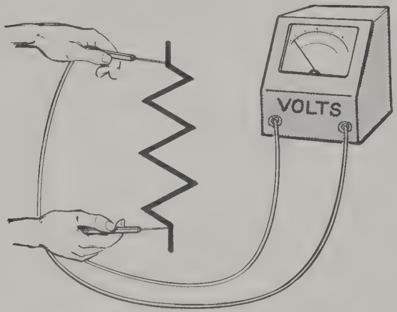
Here is another problem in connection with the circuit of figure 1. Let us suppose that the receiver is inoperative and that the trouble has been pinpointed to the IF stage--- the tube apparently is not conducting. This possibility seems to be confirmed by the voltage readings; screen and plate voltage readings are taken at points C and D, respectively, and these readings are just a little higher than the recommended values, but the meter reads zero at the grid of the tube.


GENERAL TROUBLE SHOOTING PROCEDURES
• CHECK THE UNIT AND SYSTEM FOR NORMAL OPERATION.

The Final Proof of any Repair is by Reestablishing Normal System Operation.

The tube is replaced, but the readings remain unchanged! Further voltage checks are taken with the voltmeter placed between plate and cathode. The reading is zero. Obviously the cathode circuit is at fault, and the specific trouble would seem to be an open cathode resistor. There can be no plate current if the cathode resistor is open, and an open cathode would also explain the zero reading previously obtained at the grid, for there should be some grid current even if there were no plate voltage, provided the cathode circuit is intact.

The voltmeter is now connected directly across the cathode resistor. If the cathode is open, this will have the effect of substituting the high resistance of the voltmeter for that of the cathode resistor. Even with this high resistance there should be some plate current, since cathode bias alone cannot entirely cut off plate current. Again our suspicions are confirmed; the receiver now operates, although the output is below normal. As a further quick check, the cathode may be momentarily shorted to ground.



Voltage Measurements are Always Made by Placing the Voltmeter in Parallel with the Unit Being Tested.

Our diagnosis can now be verified by turning off the power and placing an ohmmeter directly across the cathode resistor, between point A and ground. The open resistor should be immediately evident.

The tube should be removed from its socket when making this ohmmeter test, or it should be allowed to cool off, at least; otherwise, if the tube is still warm, care must be taken to connect the positive lead (internal battery) of the ohmmeter to the cathode. If the ohmmeter connections are reversed (and if the tube is still hot), the tube will conduct grid current through the meter, which might lead to the conclusion that there is resistance in the circuit even though the cathode is actually open.

Tips On Using the Voltmeter

The first thing to remember when using a voltmeter is that this instrument is always placed in parallel with some portion of an operating circuit in order to determine the voltage drop at that portion of the circuit. When making DC voltage measurements, the meter polarity must always be observed. The positive test prod of the meter is placed at the point nearest the positive side of the source; the negative test prod is placed at the point of the circuit nearest the negative terminal of the source.

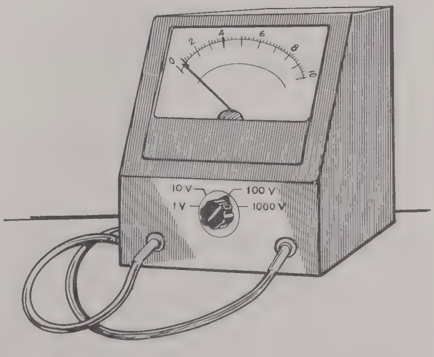
Unless the supply voltage is known, it is always best to start at a high scale on the voltmeter. If the reading is too low, the meter may then be switched to a lower scale. If the highest voltage in a unit is about 200 volts (as in a receiver), it is not necessary to start at the 1000-volt scale; the 300 volt range is high enough.

When a VTVM is used, it is permissible to switch to the scale which provides the most readable meter deflection. A low sensitivity meter, however, will readily upset the operation of some circuits in many cases, actually changing the circuit voltages while the meter is connected. This meter will have the least effect upon the circuit when the higher ranges are used. On the ten-volt range, for example, a meter may offer as little as 10,000 ohms of internal resistance.

When making voltage tests, the entire circuit operation must be studied and understood if the meter readings are to be intelligently interpreted. Perhaps we can best illustrate this by an example. Figure 2 shows the circuit of a typical voltage amplifier --- actually, the noise amplifier circuit of a particular Motorola receiver. A VTVM shows about 200 volts for the B supply, which is normal. The recorded plate voltage (plate to ground) is nearly 200 volts, and the screen voltage is about 100 volts. The cathode voltage (between cathode and ground) is considerably higher than normal, and there is no voltage reading at all between plate and cathode, nor between screen and cathode. This indicates that the tube is not conducting.

The voltmeter indicates zero volts across R6, but 100 volts across R5. The tube might be nonconductive, but there is a greater probability that the cathode circuit may be open, since you will remember that the voltage between both screen and plate (with respect to the cathode) was zero. This indicates an open cathode circuit rather than a bad tube. A further check results in obtaining a voltage reading across R3 in the cathode circuit, but not across R2. The zero voltage across R2 means that the cathode circuit (not R2) is open. The reading across R3 indicates that R3 is open, the circuit now having been completed by the meter! By replacing R3, the circuit is restored to normal.

This analysis may be more easily understood if we consider the complete plate circuit of figure 2 independently, as shown in figure 3. The tube can be regarded as a resistor, and it is shown as Rt. There are thus four series "resistors" between B plus and ground. Let us assume that one of these resistors (R3) is open. The circuit is incomplete and there is no current through any of the resistors. Also, since there can be no voltage across the resistors, the circuit is still incomplete even when the meter is placed across either R6, Rt, or R2, and the voltage reading must still be zero. When placed across R3, however, the meter completes the circuit and records a voltage. This is exactly what happened in the analysis above, the reading across R3 indicating an open resistor.



The Highest Meter Range Giving a Readable Deflection Provides the Most Accurate Voltage Readings.

A question may arise in connection with the 100 volts originally recorded at the screen when the tube was not conducting. If there was no current through the tube, you might ask, why is there a voltage drop across the screen resistor? An examination of figure 2 will show that resistors R4 and R5 form a voltage divider between B plus and ground. This will result in a lower potential at the screen, independent of screen current. This will be further decreased when the screen draws current through R5, due to the increased voltage drop across R5.[2]

AC Voltmeter

The AC voltmeter must be used when measuring AC voltages. The AC voltmeter is similar to the DC voltmeter, as far as the foregoing instructions are concerned, but no consideration need be given to the polarity of the AC test leads. Any AC measurements made by the serviceman are almost exclusively of the low-frequency type, and in this discussion we will be concerned only with such AC measurements.

While other types of AC meters are available, most of those used by the serviceman include a rectifier which changes the AC to a comparable DC and then indicates the amount of DC on the meter. Some use an amplifier stage or two to give the meter greater sensitivity.

The meter may respond to either the peak, the RMS or the average value of AC, although in most cases the meter indicates the RMS value. In using his meter, the technician should know whether the reading corresponds to the RMS (effective) or to the peak value. The dial of the meter is usually marked according to what is recorded.

Resistance Testing

An ohmmeter is essentially a source of voltage (a battery) in combination with a meter and various current limiting resistors. It is used to determine whether a particular component or circuit will conduct DC. Knowing the current through the part or circuit being measured, and with a fixed voltage source which is also known, the resistance can be read directly from the calibrated scale of the meter.

Because the ohmmeter contains its own source of voltage, there must be no other voltage used in connection with the equipment being measured. Furthermore, sensitive meters and other low-current devices must be removed before applying the ohmmeter. While this latter precaution is seldom necessary in two-way equipment, the power must always be removed, and all large capacitors discharged. Large capacitors, particularly electrolytics may retain a charge long after the power has been turned off. If such capacitors are allowed to discharge through the ohmmeter, the meter movement may be damaged.

When using the ohmmeter to analyze circuits or components, it is particularly necessary to take the entire circuit into consideration.

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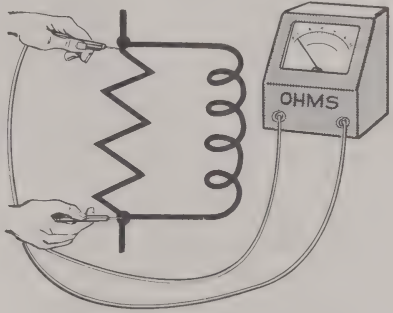
2. See Test Methods, section 2, pages 5-11.

An ever recurring problem when using the ohmmeter is the existence of DC paths in parallel with the component or circuit being measured.

The circuit of figure 4, showing the second limiter and last audio output stage of a Motorola receiver, is an example.

Finding that the voltages of the second limiter are not correct, and suspecting the existence of trouble in the grid circuit, the serviceman makes a quick resistance check between grid and ground. The meter shows that there is a conductive path. This information alone is not sufficient, however, for grid resistor R1 may be open; the reading may be due to the circuit in parallel with R1, composed of R4 and R5. Now, the grid-ground reading should be approximately 100 k, the value of the grid resistor. The parallel path through R4 and R5, however, has a resistance of 2.5 meg. If R1 is open there is still a complete grid path for DC, it is true, but the extremely high resistance of this "parallel path" may impair the operation of the receiver; it may easily be the cause of the incorrect voltage readings. This illustrates the importance of checking a circuit or component for the correct amount of resistance as well as for an open or short.

Another problem involving the ohmmeter can be illustrated before leaving figure 4 Let us suppose that the receiver is "dead," that is, nothing is heard in the speaker. Let us also suppose that unsquelching the receiver and turning the volume full on doesn't help. Meter readings are taken on the test set and they indicate that the trouble is possibly in the audio stage (although there still is no sound from the speaker, the voltage checks are all normal for the audio output stage). The final deduction is that the output transformer secondary is open.



Parallel Paths Within a Circuit Often Give Erroneous Resistance Readings.

The power is turned off, and we prepare to check the continuity with the ohmmeter. Note, however, that the speaker is in parallel with the transformer secondary. Placing the ohmmeter across the secondary terminals of the transformer would be meaningless in this case. It would still be difficult to know which unit was at fault. While the resistance value of the two units in parallel is lower than that of either unit alone, this resistance is so low that it would be impossible to know which one was open. The only logical procedure in a case like this is to disconnect one of the wires leading to the speaker and then check the two parts separately.[3]

Measuring Leakage In Capacitors

A problem often encountered when trouble shooting communications equipment involves the isolation of capacitors which are not shorted, but are merely "leaky." The defective capacitor, not readily located by a resistance check, may have developed a leakage resistance in the order of one megohm, for example. In many instances, DC voltage changes will occur in the circuits at each side of the leaky capacitor. As a result, the overall operation of the entire unit becomes unsatisfactory.

A leaky capacitor can sometimes be identified by measuring the voltages at each side of the unit. The capacitor in figure 5A may be used to couple any of the audio stages, or it may be used between stages in the IF section. The plate load of the first tube may consist of a resistor (as in figure 5A) or it may be a tuned tank. Some stages may have a large value of resistance, while others may have less than 100,000 ohms--even a few ohms where only a tuned circuit is used. In any case, the change in the voltage at the grid of the next stage is important, because of the change of bias which results. An example will show how this affects the meter readings of the stage.

Let us suppose that the coupling capacitor of figure 5A has a leakage of about 5 megohms, and that the grid resistor (R2) is about 50,000 ohms (47K actually). The leaky capacitor (Rc) thus completes a series circuit between B plus and ground, as shown in figure 5B. The voltage will divide, in this circuit, according to the resistance of the three series resistors. Most of the voltage drop will be across Rc which has 100 times the resistance of R2 and there will be but a few volts across R2 and R1. Thus, a meter placed across R2 will read only a few volts at most, and this may be disregarded as a major source of trouble. Perhaps the leaky capacitor may not be causing much trouble at this particular moment, but there is a strong probability that the leakage will gradually increase to a point where the operation of the equipment is seriously affected. It is thus important to recognize this leakage and replace the unit at once.

In many circuits the signal applied to the grid of the stage produces enough grid-leak bias to make the grid negative with respect to ground, and this leaky capacitor may not be detected; while the leaky capacitor permits the application of some positive voltage from the plate circuit of the preceding stage to the grid, the latter shows a negative voltage due to the large grid-leak bias. By removing the second tube, however, the positive voltage will be readily disclosed. With the tube removed, the grid cannot

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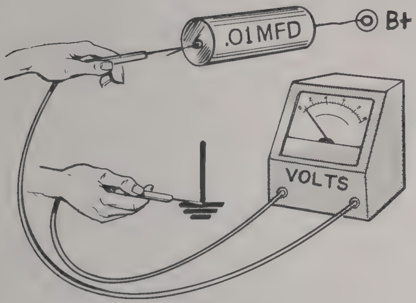
3. See Test Methods, section 2, pages 12 and 13.



A Voltmeter in Series With a Capacitor and Connected Between B+ and Ground Gives a Reliable Check for Leaky Capacitors.

draw current and the negative bias is thus removed.

A more conclusive check can be made by disconnecting the grid side of the capacitor from the grid and placing the meter between the loose end of the capacitor and ground. The circuit is shown in figure 5C, where R2 has been replaced by a meter; if the meter is a VTVM, this resistance will now be about 10 or 11 megohms. Most of the resistance of the series circuit is now represented by the meter, and the voltage drop will be greatest across the VTVM.

It is possible that when the meter leads are first connected, the capacitor will be charged by the B+ supply; in this case the meter will show a sharp initial deflection which decreases as the capacitor approaches its full charge. If the VTVM returns to zero voltage (measured on a low-voltage scale), the capacitor is not defective. If the meter has a continuous voltage reading, however, the capacitor is leaky and should be replaced. When making a test of this kind, a high-voltage scale should be used at first so that the initial charging of the capacitor does not damage the meter movement. As the amount of deflection decreases, the meter may be returned to a lower range.

The voltmeter may thus be used to check the relative ability of a capacitor to charge, giving a relative indication of the capacitance itself. The deflection of a given meter is directly dependent on (1) the amount of supply voltage and (2) the capacitance of the unit being checked. Small capacitors, about .001 ufd and lower, do not cause an appreciable amount of initial meter deflection.[4]

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4. See Test Methods, section 2, pages 19-25.

STUDENT NOTES

STUDENT NOTES

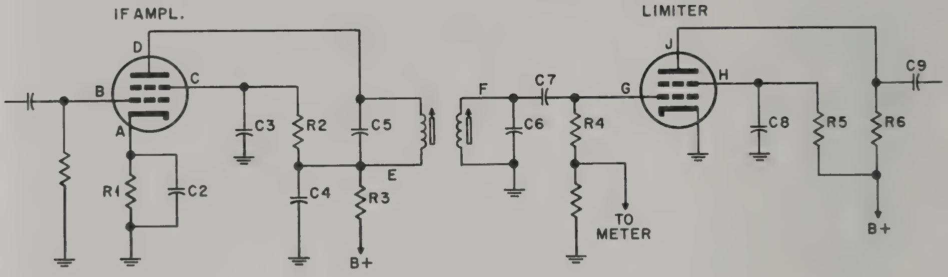

FIGURE 1

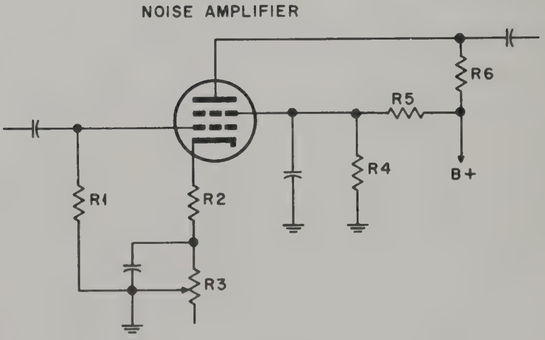

FIGURE 2

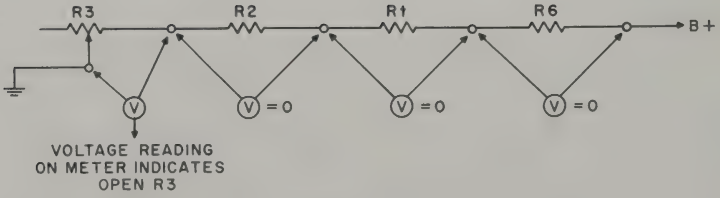

FIGURE 3

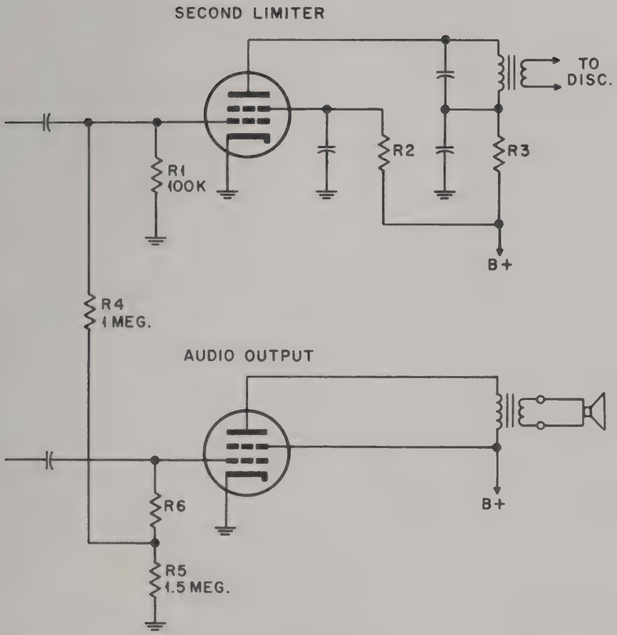
SECOND LIMITER
TO DISC.
R1 100K
R2
R3
B+
R4 1 MEG.
AUDIO OUTPUT
B+
R6
R5 1.5 MEG.

FIGURE 4

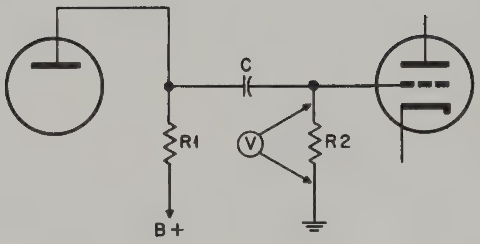

FIGURE 5A

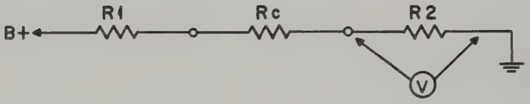

FIGURE 5B

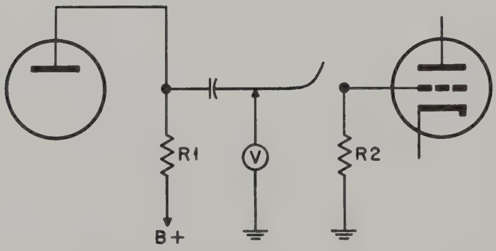

FIGURE 5C

national
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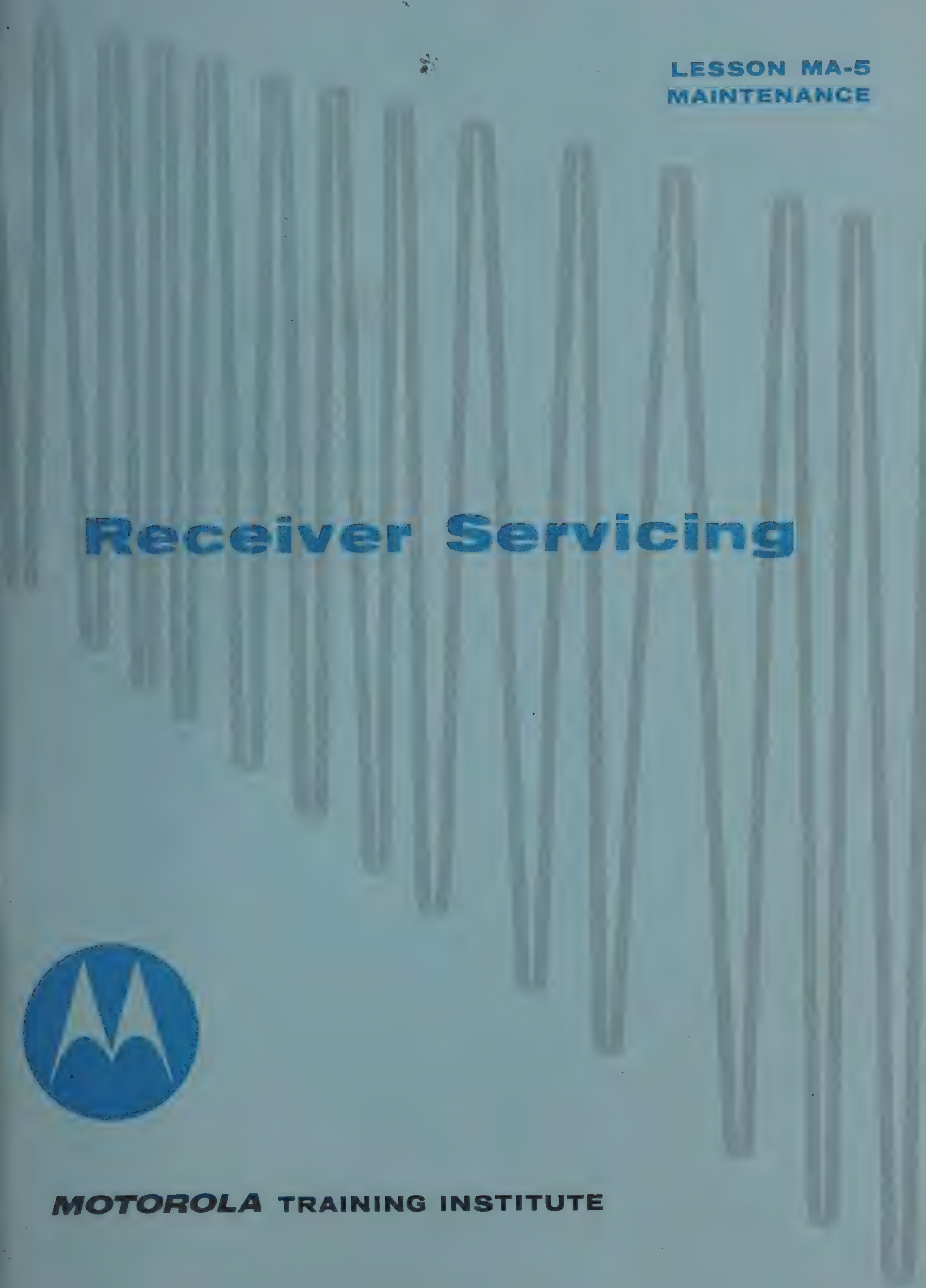
A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON MA-5
MAINTENANCE



Receiver Servicing

MOTOROLA TRAINING INSTITUTE

A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON MA-5
MAINTENANCE

Receiver Servicing

—one of a series of lessons on two-way FM communications—

MOTOROLA TRAINING INSTITUTE
4501 W. AUGUSTA BLVD., CHICAGO 51, ILLINOIS
APPROVED BY THE STATE OF ILLINOIS
DEPT. OF REGISTRATION AND EDUCATION

PREFACE

This is one lesson of a complete Motorola Home-Study Course which presents to the Service Technician both the principles of operation and the maintenance of two-way FM radio systems. The program covers mobile, portable and base station equipment, including the latest transistorized units.

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RECEIVER SERVICING

Lesson MA-5

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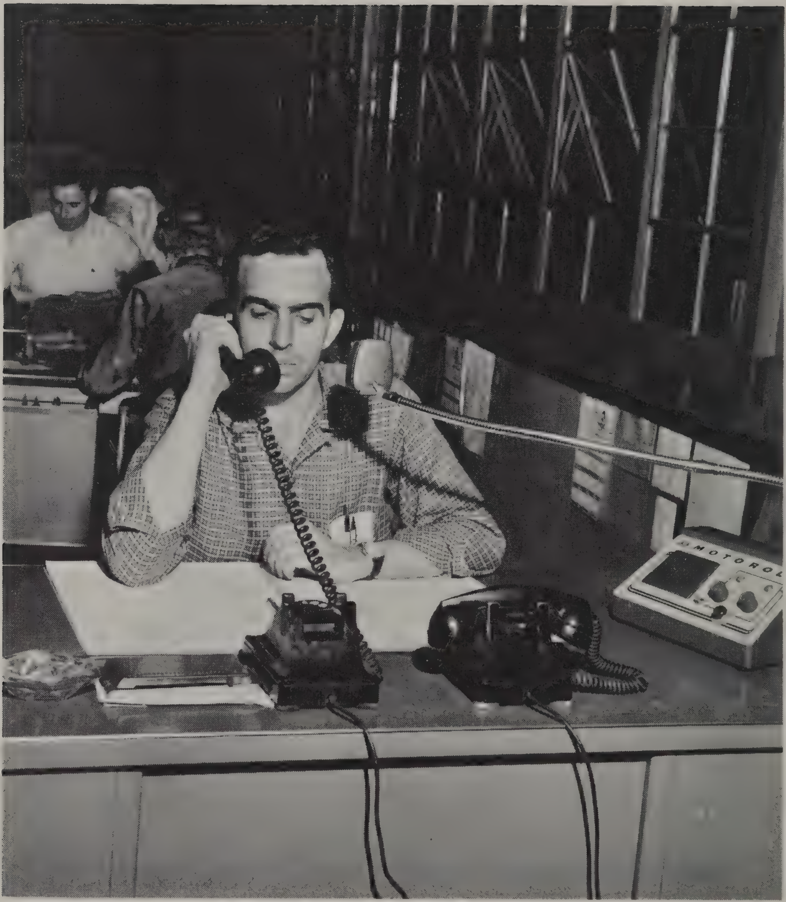
OSCILLATION. . . . . Page 14

NOTICE

Diagrams and figures referenced in text are “fold-outs” in back of each lesson, for use while studying. The Examinations are also there.



Trucking dispatchers take only seconds to translate telephone pickup orders to radio dispatch calls. Many trucking companies are radio equipping all their pickup and delivery vehicles.

RECEIVER SERVICING

Lesson MA-5

Introduction

In this lesson we shall discuss procedures for quickly locating and correcting troubles within the two-way communications receiver. We shall concern ourselves primarily with the location and correction of a single fault, since a receiver rarely has more than one major trouble. If more than one fault does occur, we must find and correct them one at a time.

Before starting our discussion about receiver trouble shooting, we must assume that previous tests have been made which definitely establish the receiver as the offending unit. That is, we must assume that the power supply and the antenna system are normal.

The specific procedure for trouble shooting the receiver will vary considerably for each service problem; we may use one technique for the receiver in the vehicle and another for the receiver at the base station. The mobile receiver is the more common of the two, so we shall start our discussion with this unit.

The Mobile Receiver

The Trouble-Isolation Chart in figure 1 will serve as a useful step-by-step guide in trouble shooting the receiver. It lists a number of possible troubles and suggests corrective procedures. In this chart we assume the only test instrument available is a Motorola test set. (We are also assuming that there is no carrier frequency signal available for testing the receiver.) This chart is intended to apply specifically to the high-band receiver of figure 2, but the general procedure will apply to many Motorola receivers, of all bands.

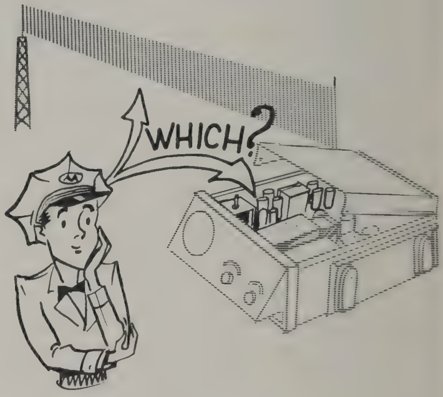
Audio Test

The first step when isolating trouble in a receiver is to turn the volume control full on and open the squelch wide (control fully counterclockwise). A loud noise should be heard in the speaker. If there is no sound, the fault is likely to be in the audio or squelch sections of the receiver. We continue with procedure 2, to the left.

Here we use the Motorola test set (either the P-8501 A/B or the TU-546). With the test set plugged into the receiver and adjusted to measure the receiver output (position 8 of P-8501 tester; position 11 of TU-546 tester), we make two checks. First, if the speaker circuit of the receiver is defective, we shall hear noise in the test speaker. Second, the test meter measures the receiver output voltage. Let's first assume that the test set shows a reading and that a loud sound is heard in the test set speaker. We may immediately assume that the speaker or its circuit in the receiver is defective. If the receiver is mounted in the trunk, the speaker is a separate unit which interconnects to the receiver through the control head. It is likely that the wiring is defective. In some models the speaker wires plug into the control head, and one of these connections may be bad. If the trouble cannot be found through visual inspection, it may be necessary to use an ohmmeter or a substitute speaker.

If there is neither noise from the speaker nor a reading on the test meter, the speaker circuit is probably, O.K. We now proceed to 3. Remove the noise rectifier tube in the squelch section and listen for sound from the speaker. Removing the noise rectifier disables the squelch section of the receiver and helps to further pinpoint the problem to either the audio circuit or the squelch circuit. If the squelch circuit is defective (if the coupling capacitor between the noise amplifier and the noise rectifier is leaky), there will be a constant positive voltage present at the DC control tube grid and the squelch will remain closed. If the squelch is to open, the negative voltage from the second limiter grid must be available and the positive voltage from the "noise section" must be removed.

If there is still sound after the noise rectifier tube is removed, try new tubes in the squelch section, procedure 4. If there is no change in the operation, the fault is in the squelch circuits and the receiver must be brought to the service bench for more detailed checks.



Failure to Hear a Message May Not be the Fault of the Receiver-- Check Carefully.

If there is no sound, however, with the noise rectifier tube removed, proceed to 5 and replace, one at a time, the audio, discriminator and second limiter tubes.

If replacing any of these tubes corrects the trouble, a high noise level will be heard and the receiver may be checked for normal operation. If, however, these tube replacements do not produce any change, the receiver must be further tested on the service bench.

RF and IF Tests

When the serviceman hears noise in the speaker after trying procedure 1, he immediately proceeds to 6 on figure 1. Here he takes readings in positions 1,2,4, 5 and 6 on the test set.

If the reading at position 2 is low (position 1 is normally low without a signal applied), the trouble is probably either in the front end or in the IF section. This includes both oscillators and mixers. It is not possible to isolate the trouble further within this large section of the receiver by making additional tests with the test set, so the best solution is to follow procedure 7. Replace the tubes, one by one, noting the change in the noise and in the meter readings, position 2 in particular.

It is sometimes possible, by noting the changes in noise level, to isolate the trouble within the entire front end of the receiver. If, upon removing the high-frequency oscillator or mixer tube, the noise does not decrease, the trouble is likely to be either in that stage or in a following stage. If the noise changes, the receiver is operating to some extent from this point on to the speaker, but some stages may be weak.

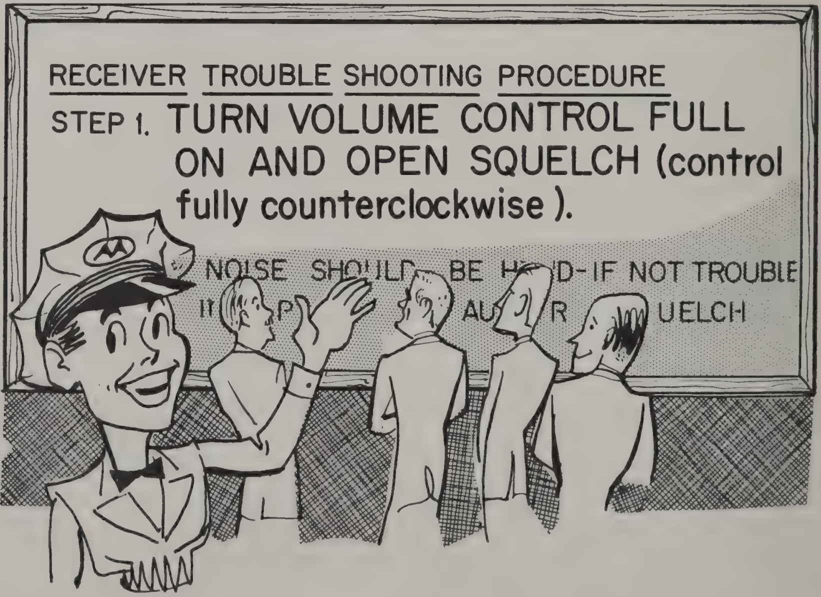
If tube substitution restores the meter reading at position 2 to near normal (and the other positions, as well), we may be reasonably sure that the trouble has been found and corrected. It is necessary, however, to completely check the receiver operation. This necessitates a brush-up on the alignment, particularly the netting of the receiver with the base station transmitter. If tube substitutions cause no change in the meter readings, we must look elsewhere before removing the set for bench servicing. First, the fault may be in the high-frequency oscillator, particularly in the matter of correct frequency. Second, the receiver may need realigning. If neither of these areas proves to be at fault, it may be necessary to further test the receiver on the service bench.

If the readings taken at metering positions 1 and 2 are normal, we next check the reading at position 6. Although this reading indicates oscillator activity, the test set doesn't actually measure the injection voltage from the oscillator plate circuit to the mixer. Besides, even if the reading at position 6 is normal, we cannot be sure that the injection signal to the mixer is at the correct frequency--the oscillator may be off frequency and require alignment.

If the reading at position 6 is too low, the next procedure, 8, is to try a new oscillator tube. If the new tube does not serve to restore operation, a crystal known to be good should be tried. If the readings are still too low, it will probably be necessary to remove the receiver from the vehicle for additional service. If the reading at position 6 returns to normal, the fault is corrected. It will still be necessary, however, to net the receiver frequency with the base station transmitter before placing it in operation.

When analyzing the readings at metering positions 4 and 5 (the primary and secondary of the discriminator), we have to take into account the readings at positions 1 and 2. If the reading at position 5 is low, we must first make sure that the readings at positions 1 and 2 are near normal. (If they are not, the fault is in the stages preceding the limiters rather than in the limiter or discriminator circuits. Thus, we are concerned with low readings at position 5 only when positions 1 and 2 are near normal.) If position 5 is still low, we should try new tubes in the limiter and discriminator stages (procedure 9 in the chart). Finally, if the reading remains low, either the receiver requires alignment or there is some other trouble for which it may be necessary to remove the receiver for bench service. If the readings are restored to normal when the new tubes are tried, it is well to check the alignment and noise idling before placing the receiver back in operation.

The reading at position 4 should normally be close to zero. When only noise is present, the idling of position 4 should be within two scale divisions of zero on the test meter. If the reading at position


RECEIVER TROUBLE SHOOTING PROCEDURE
STEP 1. TURN VOLUME CONTROL FULL ON AND OPEN SQUELCH (control fully counterclockwise).
NOISE SHOULD BE H D-IF NOT TROUBLE
UELCH

Quick, Efficient Receiver Service Requires a Complete and Logical Trouble Shooting Plan.

4 is not at zero (with no channel signal applied), it is possible that the low or high frequency IF section requires retuning. Also, a strong carrier on some nearby channel may produce "noise," causing the discriminator noise idle to swing off zero. Further checks on the receiver alignment and system netting are required.

When the reading at positions 1, 2, 4 and 5 are normal, the trouble may be due either to (1) off-channel operation of the receiver, or (2) low sensitivity in the receiver front end. For off-channel operation we may follow the suggestions under the "reading at position 6" block; for low sensitivity, follow the suggestions of procedure 7.

Using a Signal for Isolation of Trouble

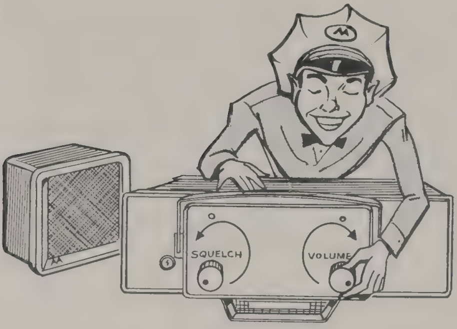
When a signal on channel frequency (such as one of the transmitters of the system) is available, it is often possible to determine the trouble more quickly and with greater reliability. The Motorola test set may also be used as a source of signal.

In general, we should start our trouble shooting in the same manner as recommended in the chart of figure 1. Unless there is some noise in the speaker (a "live" sound), there is no need for the channel signal; we already know that the trouble is likely to be in the audio or squelch circuit. Also, the reading at position 6 should be normal, for without the high-frequency oscillator working properly there would be no heterodying action and thus no IF to measure or to cause noise quieting.

Assuming then, that we have established the presence of noise in the speaker and that we have obtained a normal reading at test set position 6, we may now check any change in the readings at positions 1,2,4 and 5, with the signal applied. It is also important to note any change of noise heard in the speaker when the signal is applied.

Unless the readings in positions 1 and 2 show a reasonable increase and the noise quieting approaches 20 db, the main trouble is in the front end or IF sections of the receiver. Figure 4 is another trouble-isolation chart similar to procedure 6 of figure 1, one that we can use when a channel signal is available.

Starting with the readings at positions 1 and 2, we find three possible variations: (1) the readings do not change, (2) they change but very little, (3) they change appreciably. If the readings change very little (or not at all), and if there is little if any noise reduction, we should recheck position 6. If this is O.K., we then follow procedure 7 in figure 1. When the readings at positions 1 and 2 increase appreciably with a signal applied and some noise quieting is noted, we know that both sections of the oscillator-mixer are working normally. However, there are still two possible trouble sources. The sensitivity may be low, or the high-frequency oscillator may not be at the correct frequency.



A Quick Check On Receiver Operation is Made by Turning the Volume Full-On and Opening the Squelch.

For the low sensitivity condition, follow procedure 7 in figure 1. If this proves good, check the test set reading at position 4. Position 4 may show no change, read zero on signal, or swing away from zero. If there is no change in the reading and noise quieting, the trouble is in the limiter or discriminator stages; try replacing tubes. If this does not correct the fault, the receiver probably requires further servicing with additional test equipment. If the reading swings away from zero when a signal is applied, the high-frequency oscillator is off frequency and may be warped back to zero. (Be sure that the discriminator reads zero with a 455-kc signal.) If the reading shows zero with the signal applied, the oscillator frequency is correct; the trouble, if any, is in either the front end or in the IF stages. See the suggestions of procedure 7 in figure 1.

The readings at positions 5 and 6 do not add appreciably to our present type of trouble shooting technique, for these readings are not likely to change to any extent with an applied signal. Only if the incoming noise fails to saturate the last limiter will there be any change at position 5. There is no normal trouble that might occur which could produce a change at position 6.

To summarize our discussion about the use of a signal to help isolate trouble in the receiver, we see by comparing the readings on the meter that:

1. If the readings at 1 and 2 do not increase and there is no noise reduction, the trouble is in the front end, ahead of the limiters.

2. If there is an increase in the readings at positions 1 and 2 and in the noise quieting, the reading at position 4 immediately tells us whether the receiver is on channel or not.

When to Remove Set for Bench Service

Up to now we have dealt with the receiver in the vehicle. We have implied, however, that on occasion further servicing required its removal to the service bench, that more comprehensive testing was required than could be done with only a test set. Whether we immediately remove the radio set or test it further in the vehicle depends upon the vehicle use. A police squad car, for example, can be out of service for a limited time only. If the trouble cannot be corrected within this time, the radio must be removed for servicing.

Where spare units are available for replacement, minimum time should be spent in servicing the equipment in the car. As soon as the serviceman is convinced that the fault is not a simple one, such as a defective tube, he should replace the unit with the spare and bring the defective set to the shop. This unit, when repaired, will then become the "spare" for the next car which requires it. This procedure saves considerable time for both the serviceman and the customer. By a spare we mean a complete installation, the receiver, transmitter, and power supply. These units are assembled together on a single frame and they are removed from the housing as a single unit. The original set can be removed and the spare installed in a matter of a few minutes. The spare is then checked out with the base station and the vehicle is ready for service.

In many instances the out time of the vehicle is not so important to the owner and it may be practical for the serviceman to make more checks on the receiver and attempt to service it without removal. This is particularly true where the serviceman has additional test equipment available.

In the remainder of this lesson we will discuss several bench service procedures and techniques. These same procedures may apply in general to the receiver while still installed in the car.

Alignment

While general alignment procedures can be given for typical receivers, we shall learn more by referring to a specific receiver chassis. We shall accordingly use the Motorola Sensicon "G" receiver, shown in figures 2, 3 and 5.

Figure 2 is the schematic diagram of this receiver, and figure 5 (which also includes the alignment chart) shows the parts placement as viewed from the top. Although this is designated as the complete "bench" alignment procedure, it can also apply to receiver alignment at the vehicle.

The following test equipment will be required to align the receiver: (1) a Motorola test set and a 455-kc crystal; (2) a Motorola model TU576 signal generator (or equivalent); (3) a known source of signal at the channel frequency. A frequency meter of acceptable accuracy can be used to set the signal generator to the channel frequency.

The photo in figure 5 shows the connections between receiver chassis and test set. The power supply for the receiver is not shown, since the receiver will usually be left in the complete assembly along with the transmitter and power supply.

The first step is to align the circuits tuned to the last IF frequency, 455 kc. This requires the test set and a 455-kc crystal. The adjusting procedure for the test set will be found at the left of figure 5. We first adjust the discriminator primary. A shorting wire is connected across the secondary terminals of the transformer assembly, and the meter switched to position 5. Then, with the generator supplying a 455-kc signal to the grid (pin 1 of V106, figure 2), the primary is adjusted for a maximum reading on the meter. Resonance is indicated by a relatively sharp peak. The primary is adjusted from the bottom of the chassis. After adjusting the primary slug to resonance, the locknut is tightened. Once this adjustment has been made, it is not likely that the primary will require a readjustment for some time.

The next step is to tune the discriminator secondary. Remove the short across the secondary, switch the meter to position -4 or 4, and adjust the secondary for a zero setting, which must be midway between positive and negative peaks. The secondary slug is adjusted from the top of the discriminator transformer assembly.

The remaining 455-kc adjustments are in the IF plate circuits; the tuning procedure appears in steps 3, 4 and 5 of figure 5. The signal is coupled to the input of the Permakay filter. The level is kept low, so that the readings are always linear with any increase in signal strength. Too strong a signal will cause saturation, in which case the readings will show little or no increase. The meter is set to position 2 and L16 is adjusted for a maximum reading. With the meter in position 1, IF coils L15 and L14 are tuned for maximum. This completes the alignment of the low IF section.

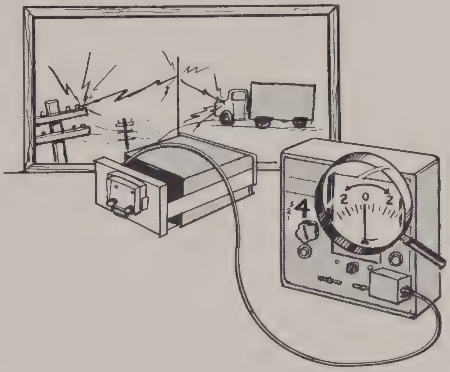
The 12-mc section is tuned next (steps 6 and 7). The 12-mc IF frequency is supplied by the signal generator, and its frequency is first adjusted for zero at the discriminator output (position 4). The 12-mc signal heterodynes with the second oscillator frequency at the second mixer, thus producing the 455-kc signal in the last IF section. If a satisfactory reading is obtained at positions 1 or 2, the signal generator is next coupled to the grid of the first mixer. If the reading is not satisfactory, however, it may be necessary to couple it to the grid of the first IF amplifier, V104. With the generator coupled to the grid of V104, coils L11, L12 and L13 are adjusted for maximum. With the generator at the first mixer grid, coils L8, L9 and L10 may be adjusted for maximum.

It is important to check the generator occasionally, making sure it remains at 12 mc throughout the adjustments. This is particularly true during the warm-up period, for the generator is likely to drift during this period. A quick check can be made by observing the reading at meter position 4; the reading must remain at zero. This completes the alignment of both the high and the low IF sections of the receiver. All that remains are the oscillator-multiplier and RF circuits.

With no signal applied and the meter at position 6, L5 is adjusted for maximum oscillator output. First, however, it is important to preset the trimmer capacitor C110 in the oscillator so that the tuning slot is parallel with the chassis. This places the oscillator close enough to its correct frequency so that the circuits will be adjusted for maximum even if a slight change of frequency becomes necessary.

After L5 is adjusted for maximum activity, the multiplier coils must be tuned. This requires a signal at the channel frequency, and the signal generator is used for this purpose. The signal generator is first set to the channel frequency in accordance with step 9 in figure 5. With the channel signal applied at the mixer or at the RF grid (antenna input), L6 or L7 are adjusted for a maximum reading at positions 1 or 2. (Unless the receiver sensitivity is maximum, it may be necessary to use position 2 for these initial adjustments.)

The RF coils are adjusted next. With the channel signal applied to the grid of the RF amplifier, L2, L3 and L4 are adjusted for a maximum reading at positions 1 or 2. If a reading can be obtained with the signal applied to the antenna input terminals, it is permissible to adjust the coils in this manner instead of injecting the signal directly at the grid.



A Properly Aligned Receiver will "Noise Balance" within Two Scale Divisions of Zero in Position 4 on the Test Set.

The antenna coil is now adjusted by applying the RF signal through a 6-db, 50-ohm pad to the antenna connector and adjusting L1 for a maximum reading at position 2. (If the reading is satisfactory, use position 1.)

The receiver is finally adjusted for the exact channel frequency. This is done by "netting" the receiver frequency to that of the transmitter with which the receiver normally operates. The transmitter must be turned on; then, with the meter in position 4, C110 is adjusted for a zero reading.

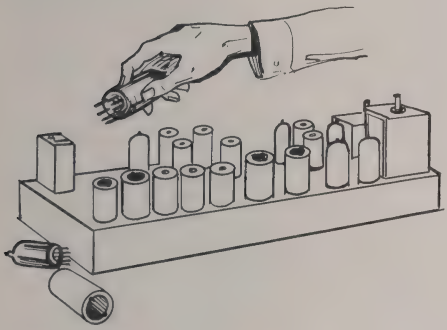
After the receiver has been netted to the base transmitter, it must be checked for "noise balance." Effective noise balance can be realized only after the receiver has been netted to the carrier it is to receive. As shown in step 13 (figure 5) of the alignment procedure, this also requires the receiver to be installed in the vehicle. The vehicle motor is left running while a signal at the channel frequency is received from the base transmitter. Ideally, this signal should cause a quieting of from 20 to 30 db. The plate coil of the first stage in the low IF section may now be retuned slightly for a reduction of ignition noise. In making this adjustment it is most important to observe the meter reading at position 2, which must not decrease more than one-half microampere (half-scale division on the meter). If the above procedure is unsatisfactory, the first IF plate coils can be used. The readings of the first IF are sharper, however, and this procedure may cause a detuning of the circuit, lowering the receiver's sensitivity. It is thus necessary to observe the meter reading at position 2 closely while making this adjustment. Noise balance is best achieved in different parts of the receiver depending upon the particular model and circuit. Always proceed according to the recommendations of the service manual.

Unless the noise adjustment is made for the exact carrier frequency which is to be received, it will not be effective when the receiver is put in actual operation. Furthermore, when the correct noise adjustment is realized, the idling of position 4 without a signal should fall within one or two microamperes of zero. This means that the discriminator balance for the noise input should be within 1 or 2 scale divisions (position 4) when the signal is removed. Failure to realize this noise idling indicates that the second IF section is not aligned to the center of the Permakay filter. When this occurs, it is best to recheck the alignment of the 455-kc circuits as well as the adjustment of the ignition balance.

Sensitivity Check

Whenever the receiver has been aligned or any general service has been performed, a sensitivity check should follow, in order to make sure that the receiver will work satisfactorily.

A sensitivity check requires a T1034A signal generator (or equivalent) and some kind of output indicating device such as a sensitive output meter. In position 8 the Motorola P8501 test set can be used as a convenient output indicator for the receiver. The quieting sensitivity of the receiver is the amount of RF signal required at the receiver input in order to reduce the receiver noise by 20 db. The squelch control is turned completely counterclockwise to open the squelch circuit, and the audio volume is adjusted for approximately 0.5 volt output. If the P8501 test set is being used, the receiver volume is adjusted for a reading of 10 on the meter; if an AC output meter is used, the volume is adjusted to any convenient value, such as 0.5 volt.



In Tube-Type Receivers, Most Troubles are Repaired by Replacing a Defective Tube.

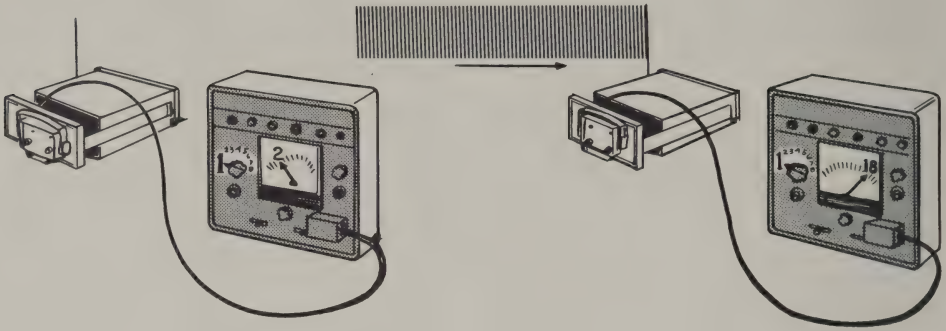
Connect the signal generator through a 6-db, 50-ohm pad to the antenna connector and place it on channel frequency by monitoring position 4 on the test set. The generator output is then returned to zero and increased until the output reading is reduced to one-tenth its original value. The generator output, in microvolts, is the receiver sensitivity. This value should be checked against the receiver specs. If the receiver is not up to full sensitivity it would be well to determine the reason and make the necessary corrections. Sensitivity may be improved by touching up the alignment in the front end of the receiver, or by substituting new tubes in the front end stages. The supply voltages, both A and B, should also be checked. After these areas have been exhausted as possible sources of poor sensitivity, check the meter readings on the test set. It may be necessary to make stage gain checks.

Stage Gain Measurements

Stage gain measurements are shown in figure 6. The instruments and terminations recommended are important if representative readings are to be secured, and they must be followed in detail. The stage gains shown in figure 6 can be realized only when the receiver is properly aligned. If there is any doubt on this score, the receiver should be completely aligned as recommended in the instruction manual.

By comparing the actual reading (with the meter in positions 1, 2, 4, 5 and 6, respectively) with the corresponding reading in the chart, an indication of the general operation of the various circuits can be obtained. By measuring the gain of the receiver at each stage, the one causing the low sensitivity is readily isolated. Voltages and resistance measurements can be made to determine the defective component within the stage.

The following example of trouble shooting by means of stage measurements is typical. Let's sup-



Comparing Meter Readings With and Without a Channel Signal is Very Helpful in Trouble Shooting the Receiver.

pose that the meter reads low in positions 1 and 2, when measuring noise input. The 12-mc input of 5 uv to pin 1 (grid) of V104 gives the correct 20-db quieting, but a 12-mc input of 3.0 uv at the mixer grid (pin 1 of V103) does not give 20 db of quieting, nor does a signal of 30.0 uv give a reading of -2 at position 1. This indicates that the gain between the grid of V103 and the grid of V104 is not correct, and the fault is probably in the grid or plate circuit of V103. Voltage checks are now made at the plate and cathode. If these readings are approximately correct, resistance tests may be made on the stage, including the plate coils. These may be tuned in the normal manner for checking the proper peaks. Failure of a coil to show a sharp peak indicates a definite fault in the tuned circuit. Open coupling capacitors must also be considered, although this condition results in sharp tuning with poor sensitivity. Because of their small capacitance, these units cannot be easily tested; it is usually better to substitute another capacitor and compare the results.

The effect of an open coupling capacitor depends on the amount of signal present as well as on the location of the capacitor. At the sensitivity level of the receiver, the relatively weak signal will find little coupling from one circuit to the next and the receiver may be completely dead. With a strong signal, however, it is very probable that the signal will be coupled from one circuit to the next even though the "coupling" capacitor may be open! Under these circumstances the receiver may operate fairly well, though its sensitivity will have been considerably reduced.

The results will also depend on whether the coupling capacitor is in the RF section or in the first IF section. Stray coupling is always more likely to occur at the higher frequencies.

When making stage gain measurements the correct procedure is to start at the last stage of the set and continue toward the antenna, until the point is located. The trouble is thus pinpointed to a particular stage in the receiver.

Discriminator Response Curve

One of the most important factors in securing clarity of the message reproduced by the speaker is for the discriminator "recovery slope" to be linear over the deviation limits of the system. This subject was discussed in the receiver lesson dealing with discriminator action. The discriminator response curve must be linear over a frequency range greater than the deviation employed by the system and in general this linearity is one and one-half to two times that of the deviation. This allows for some shift in the incoming IF signal and for possible detuning of the discriminator secondary.

The linearity of the audio recovery can be determined with the test set, using crystals 15 kc above and 15 kc below the center frequency of the last IF.

Each kilocycle of deviation in a 15-kc deviation system should produce approximately one volt at the discriminator output--at 15 kc from center frequency the discriminator output should be at least 15 volts. By comparing the output at 15 kc above center and 15 kc below center, the linearity of the discriminator will be known. A 10 per cent variation of the output voltages is permissible, but any greater difference represents too much distortion. When this occurs, recheck the alignment of the discriminator primary, the secondary, and the last IF section. If the receiver is operating on a 5-kc deviation, the output voltage should be at least 15 volts for the 5-kc deviation. These voltage checks are made at the full discriminator output, not at the input to the first audio stage. (In figure 1 this is at pin 5 of the 6AL5 discriminator tube base.)

Where the DC type of volume control is used, the output of the second limiter will be controlled to some extent by the setting of that control. For an accurate check, therefore, the volume control must be set temporarily at maximum.

Audio Stage Gain Measurements

While normal problems in the audio stage usually will not often require stage gain measurements, a system for determining relative audio levels should be known. In order to check the entire audio section, it is also important to test the deemphasis section. The audio input should thus be fed to the discriminator output, pin 5 of the 6AL5 tube socket.

For discussion purposes, typical readings were taken for the receiver circuit of figure 1. It should be kept in mind, however, that these figures are typical of one receiver only, and a 10 per cent variation from one receiver to another of the same model may be expected. Moreover, different receiver models have different gain requirements, and great variations may be found. The test signal was taken at 1000 cps. With frequencies other than 1000 cps different gains should be expected.

The volume and audio level controls were first adjusted to maximum; the 1000-cps signal was then applied to pin 5 of the 6AL5 socket and adjusted to a level of 10 volts. The voltage at the grid of the first audio amplifier was 0.5 volt. This loss can be attributed to the deemphasis network and the large resistor R141 in series with the audio level control. The audio output at the plate of the first amplifier was nearly 9 volts, a stage gain of 18 (0.5 volt to 9 volts), or 25 db. There is some loss in the coupling from the first audio stage to the power amplifier, and the voltage at the grid of the 6AQ5 was 8.5 volts. The output voltage was measured at both the plate of the tube and at the lead to the voice coil (transformer secondary). These voltages were 110 volts and 2.5 volts, respectively. The output stage is designed to deliver a specific amount of power to operate the speaker, and the desired power for this receiver is two watts. The power output equals the voltage squared, divided by the resistance. The square of 2.5 is 6.25; dividing this by 3, the impedance of the voice coil, results in more than 2 watts.

By making such audio measurements on any receiver you may be servicing, you will know what the voltage levels should be when the equipment is operating in a normal manner. Then, when something happens, a second set of readings may be taken for the audio section and the results compared. These typical readings may be recorded for quick reference at any time. In fact all the readings of any receiver should be kept for future reference. This data is most valuable, for it immediately shows which circuits have changed since the last readings were taken.

When making stage gain measurements, it must be remembered that the signal level will have some effect on the amplification of the various stages, particularly in the audio section. The gain for a strong audio frequency signal may be considerably different from that of a weak audio frequency signal. More accurate results can be obtained by using a typical signal level such as the one illustrated above. Such a signal also indicates whether or not the audio power output is up to par. Too large a signal overdrives the tubes, causes distortion, and lowers the net gain.

Oscillation

In a two-way communications receiver, oscillation may take place without the operator or serviceman being aware of the fact. Oscillation within one of the stages or sections of a receiver is thus a problem which must be anticipated by the serviceman.

Oscillation may have various effects upon the receiver, depending upon the strength of the oscillation and where it is taking place. One of the most common effects is a partial quieting of the noise usually heard in the speaker when the receiver is unsquelched. The oscillation acts like a signal at the limiters, reducing the noise. Following this noise reduction, we can also expect that the noise level might be so low that the squelch circuit would be unable to squelch the receiver.

It is a characteristic of most oscillations that they produce higher than normal meter readings for the limiter grid circuits and the discriminator primary. Moreover, the discriminator secondary reading may be full scale in either direction rather than at zero, and alignment adjustments may be critical and erratic.

Trouble-shooting techniques such as "tube-pulling" and "grid-grounding" usually show which stage or section is oscillating. Oscillation usually occurs in the RF section of the receiver or in the last IF section, and pulling the front end tubes will usually pinpoint the oscillation to one of these two areas.

Common causes of oscillation are open bypass capacitors, broken ground leads, coupling capacitors out of position (away from the chassis instead of next to the chassis), ungrounded shields, and excessive supply voltages. The oscillating section of the receiver can often be found by bringing the hand close to the suspected section and noting the change in the meter readings, or in the sound coming from the speaker. When testing for oscillation, the input should always be terminated either into its antenna or into a 50-ohm load. Unless this is done, the RF stage is likely to oscillate.[1]

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1. See Test Methods, section 2, pages 61-86, and section 3, pages 5-10.

STUDENT NOTES

STUDENT NOTES

RECEIVER TROUBLE-ISOLATION CHART
NO SIGNAL AVAILABLE

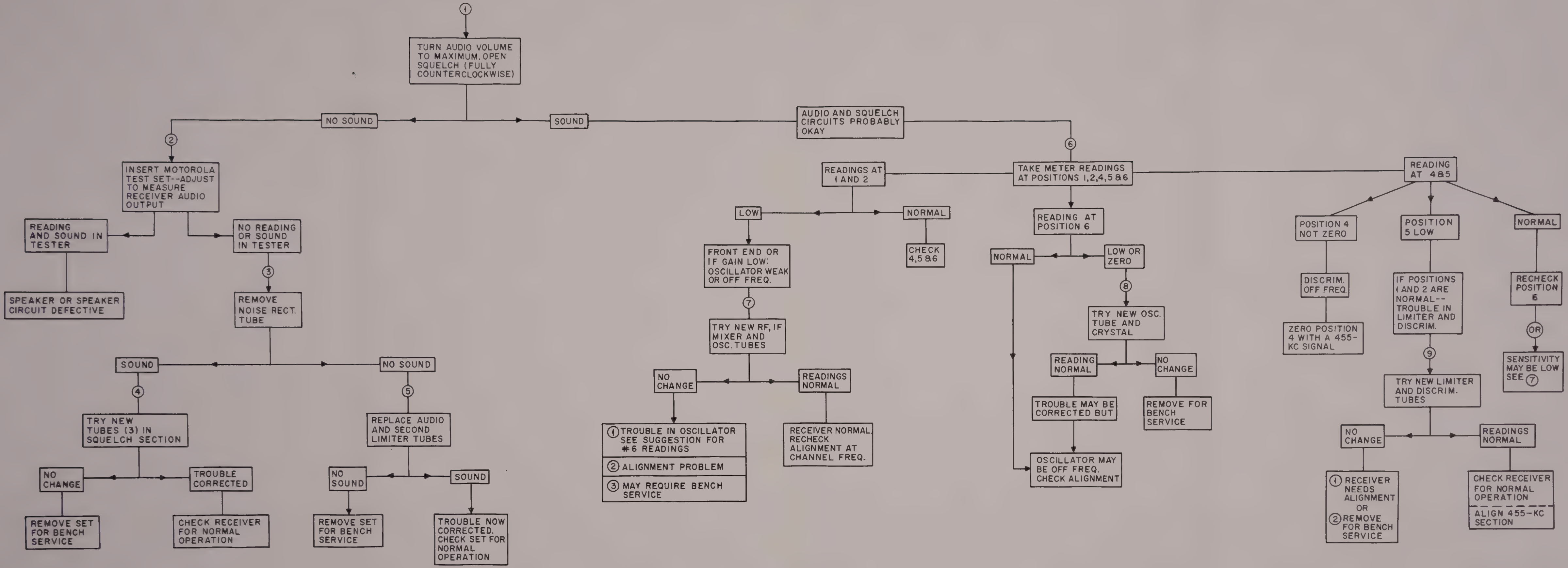
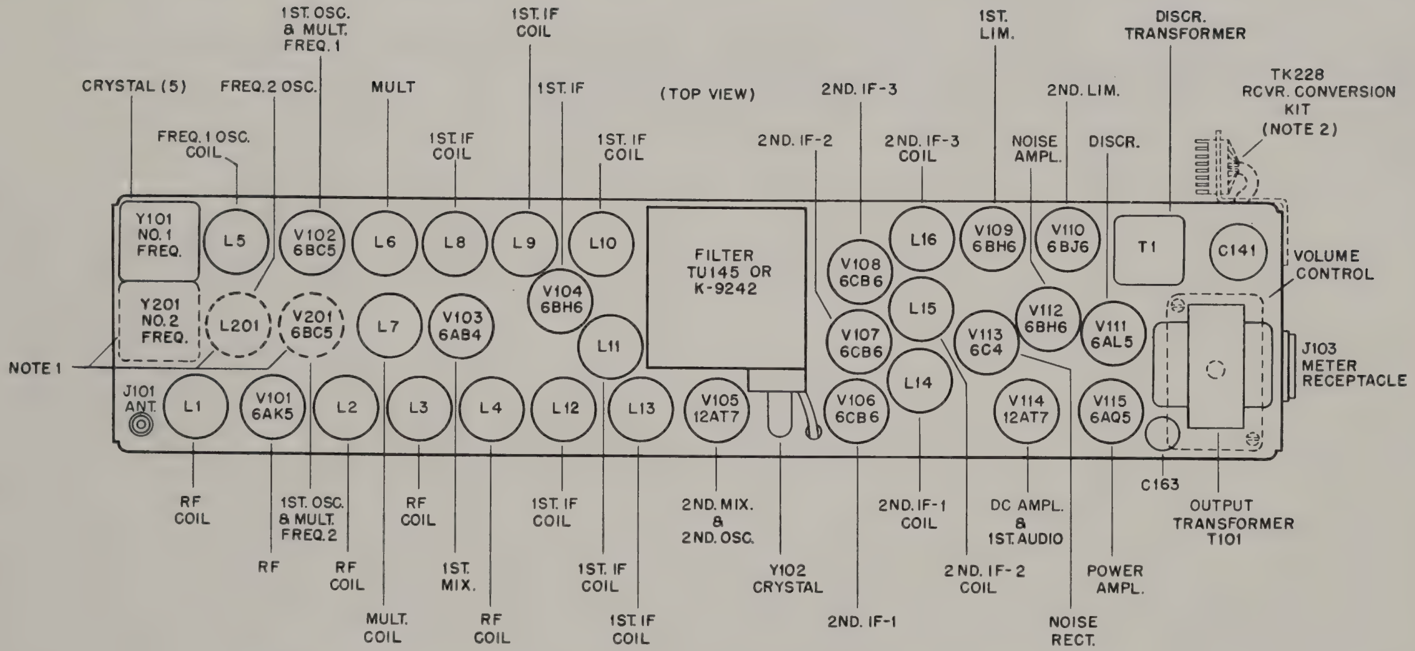
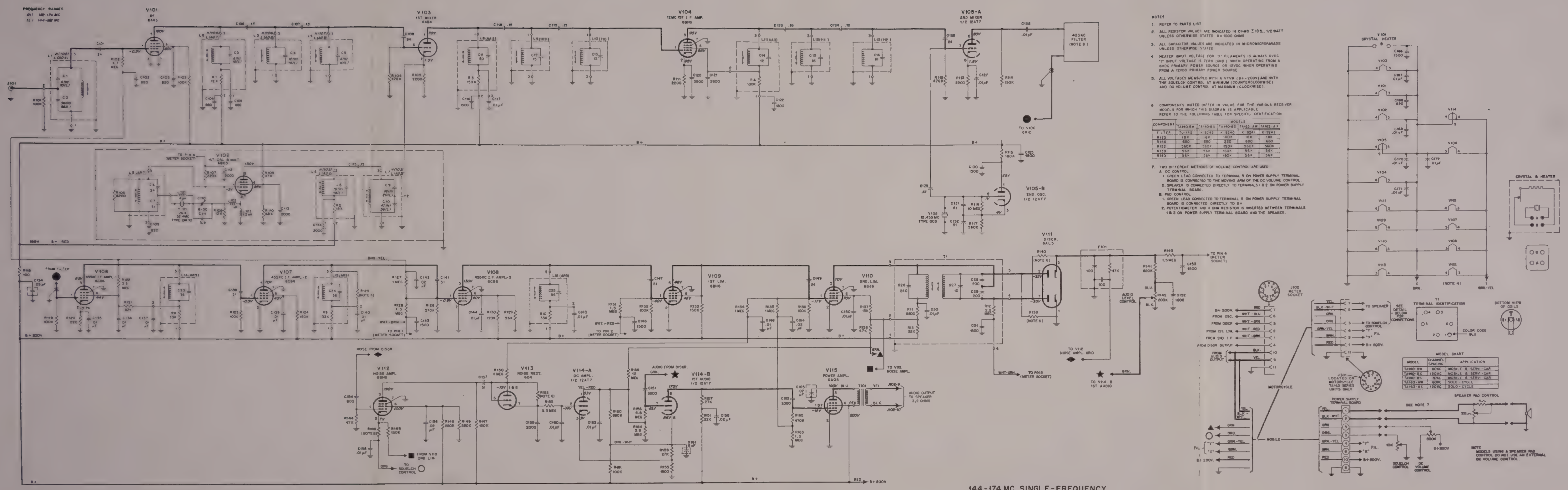

①
TURN AUDIO VOLUME TO MAXIMUM. OPEN SQUELCH (FULLY COUNTERCLOCKWISE)
NO SOUND
SOUND
②
INSERT MOTOROLA TEST SET--ADJUST TO MEASURE RECEIVER AUDIO OUTPUT
READING AND SOUND IN TESTER
SPEAKER OR SPEAKER CIRCUIT DEFECTIVE
NO READING OR SOUND IN TESTER
③
REMOVE NOISE RECT. TUBE
SOUND
④
TRY NEW TUBES (3) IN SQUELCH SECTION
NO CHANGE
REMOVE SET FOR BENCH SERVICE
TROUBLE CORRECTED
CHECK RECEIVER FOR NORMAL OPERATION
NO SOUND
⑤
REPLACE AUDIO AND SECOND LIMITER TUBES
NO SOUND
REMOVE SET FOR BENCH SERVICE
SOUND
TROUBLE NOW CORRECTED. CHECK SET FOR NORMAL OPERATION
AUDIO AND SQUELCH CIRCUITS PROBABLY OKAY
⑥
TAKE METER READINGS AT POSITIONS 1,2,4,5 & 6
READINGS AT 1 AND 2
LOW
FRONT END OR IF GAIN LOW: OSCILLATOR WEAK OR OFF FREQ.
⑦
TRY NEW RF, IF MIXER AND OSC. TUBES
NO CHANGE
① TROUBLE IN OSCILLATOR SEE SUGGESTION FOR #6 READINGS
② ALIGNMENT PROBLEM
③ MAY REQUIRE BENCH SERVICE
READINGS NORMAL
RECEIVER NORMAL. RECHECK ALIGNMENT AT CHANNEL FREQ.
NORMAL
CHECK 4,5 & 6
READING AT POSITION 6
NORMAL
OSCILLATOR MAY BE OFF FREQ. CHECK ALIGNMENT
LOW OR ZERO
⑧
TRY NEW OSC. TUBE AND CRYSTAL
READING NORMAL
TROUBLE MAY BE CORRECTED BUT
NO CHANGE
REMOVE FOR BENCH SERVICE
READING AT 4 & 5
POSITION 4 NOT ZERO
DISCRIM. OFF FREQ.
ZERO POSITION 4 WITH A 455-KC SIGNAL
POSITION 5 LOW
IF POSITIONS 1 AND 2 ARE NORMAL-- TROUBLE IN LIMITER AND DISCRIM.
⑨
TRY NEW LIMITER AND DISCRIM. TUBES
NO CHANGE
① RECEIVER NEEDS ALIGNMENT OR ② REMOVE FOR BENCH SERVICE
READINGS NORMAL
CHECK RECEIVER FOR NORMAL OPERATION
ALIGN 455-KC SECTION
NORMAL
RECHECK POSITION 6
OR
SENSITIVITY MAY BE LOW SEE ⑦

FIGURE 1



NOTES:
1. Y201, L201 & V201 ARE USED ON 2 FREQUENCY MODELS ONLY.
2. TK228 RECEIVER CONVERSION KIT USED ON TA163-A SERIES MODELS ONLY.

144-174 SENSICON "G" RECEIVER
PARTS LOCATION DETAIL
FIGURE 3



144-174 MC SINGLE-FREQUENCY
SENSICON "G" RECEIVER
SCHEMATIC DIAGRAM
FIGURE 2

NOTES:

1. REFER TO PARTS LIST
2. ALL RESISTOR VALUES ARE INDICATED IN OHMS ± 10%, 1/2 WATT UNLESS OTHERWISE STATED. K = 1000 OHMS
3. ALL CAPACITOR VALUES ARE INDICATED IN MICROMICROFARADS UNLESS OTHERWISE STATED.
4. HEATER INPUT VOLTAGE FOR "X" FILAMENTS IS ALWAYS 6VDC "Y" INPUT VOLTAGE IS ZERO (GND) WHEN OPERATING FROM A 6VDC PRIMARY POWER SOURCE OR 12VDC WHEN OPERATING FROM A 12VDC PRIMARY POWER SOURCE
5. ALL VOLTAGES MEASURED WITH A VTVM (B+ = 200V) AND WITH THE SQUELCH CONTROL AT MINIMUM (COUNTERCLOCKWISE) AND DC VOLUME CONTROL AT MAXIMUM (CLOCKWISE).
6. COMPONENTS NOTED DIFFER IN VALUE FOR THE VARIOUS RECEIVER MODELS FOR WHICH THIS DIAGRAM IS APPLICABLE REFER TO THE FOLLOWING TABLE FOR SPECIFIC IDENTIFICATION

COMPONENT	MODELS				
	TA140-BW	TA140-BX	TA140-BS	TA163-AW	TA163-AX
FILTER	TU-145	K-9242	K-9240	K-9241	K-9242
R125	18K	18K	100K	18K	18K
R146	680	680	220	680	680
R152	560K	560K	820K	560K	560K
R139	56K	56K	180K	56K	56K
R140	56K	56K	180K	56K	56K

7. TWO DIFFERENT METHODS OF VOLUME CONTROL ARE USED
   A. DC CONTROL
      1. GREEN LEAD CONNECTED TO TERMINAL 5 ON POWER SUPPLY TERMINAL BOARD IS CONNECTED TO THE MOVING ARM OF THE DC VOLUME CONTROL.
      2. SPEAKER IS CONNECTED DIRECTLY TO TERMINALS 1 & 2 ON POWER SUPPLY TERMINAL BOARD.
   B. PAD CONTROL
      1. GREEN LEAD CONNECTED TO TERMINAL 5 ON POWER SUPPLY TERMINAL BOARD IS CONNECTED DIRECTLY TO B+
      2. POTENTIOMETER AND 4 OHM RESISTOR IS INSERTED BETWEEN TERMINALS 1 & 2 ON POWER SUPPLY TERMINAL BOARD AND THE SPEAKER.

MODEL CHART

MODEL	CHANNEL SPACING	APPLICATION
TA140-BW	60KC	MOBILE & SERVI-CAR
TA140-BX	120KC	MOBILE & SERVI-CAR
TA140-BS	30KC	MOBILE & SERVI-CAR
TA163-AW	60KC	SOLO-CYCLE
TA163-AX	120KC	SOLO-CYCLE

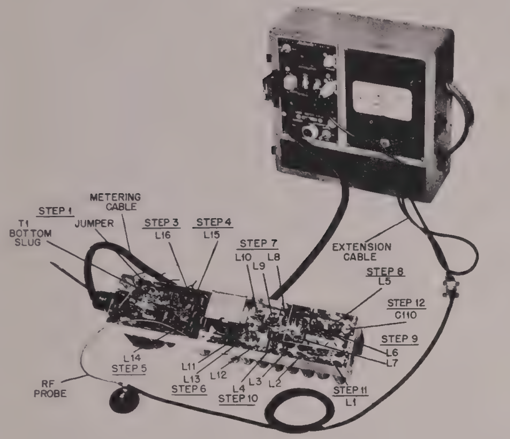
NOTE
MODELS USING A SPEAKER PAD CONTROL DO NOT USE AN EXTERNAL DC VOLUME CONTROL.

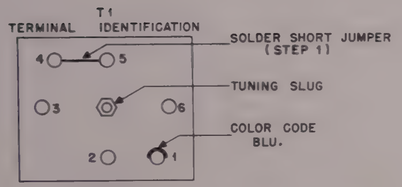
STUDENT NOTES

COMPLETE BENCH ALIGNMENT PROCEDURE FOR MOTOROLA SENSICON "G" RECEIVER

HOW TO SET UP THE P-8501-A TEST SET FOR DISCRIMINATOR AND 455 KC. I.F. ALIGNMENT

1. Set the REC.-XMTR.-0-50 UA. switch to the REC. position.
2. Plug a 455 kc. crystal into the two-pin crystal socket.
3. Set the GRID CURRENT-METER-FIELD STRENGTH selector switch to the GRID CURRENT position.
4. Set the ATTENUATOR control for maximum output (10).
5. Place the test set ON-OFF switch in the ON position. (Test set operates on internal battery. Conserve battery life by keeping switch OFF when set is not in use.)
6. Adjust the frequency control (ADJ) for a maximum meter reading.
7. Set the ON-OFF switch to the OFF position.
8. Set the GRID GURRENT-METER-FIELD STRENGTH switch to the METER position.
9. Plug the test set metering cable into the METER receptacle on the receiver chassis.
10. Connect one end of the test set extension cable to the RF OUTPUT jack on the test set. Connect the other end of the extension cable to the RF probe cable.





DETAIL A

HOW TO SET UP THE MODEL 80 SIGNAL GENERATOR FOR 12 MC I.F. ALIGNMENT

1. Couple the signal generator output loosely to the grid (pin 7) of V105. Couple just enough input to give a small meter reading.
2. Set the test set selector switch to position +4 or -4. Set the ON-OFF switch to the ON position.
3. Set the signal generator frequency for approximately 12 mc.
4. Locate the exact 12 mc. point by rotating the generator dial back and forth around the 12 mc. setting until you obtain a meter reading of exactly zero (position 4). The meter reading should go above and below zero as the dial is rotated. Leave the generator set for zero meter reading. Make sure the signal remains constant throughout the alignment (generator may drift).

PRIVATE LINE RECEIVER
BENCH ALIGNMENT CHART

FIGURE 5

STEP	STAGE, TEST CONDITIONS AND PROCEDURE	ALIGNMENT FREQUENCY	ADJUSTMENT	METERING	
				SWITCH POS.	READING
1	DISCRIMINATOR PRIMARY—Solder a short jumper across terminals 4 and 5 of the discriminator secondary coil (see DETAIL A, lower left). Set up the P-8501-A Test Set as described in the left hand column. Place the test set selector switch in position 1 and set the ON-OFF switch to the ON position. Move the RF probe around near pin 1, V106, until the meter reading is at least 15 ua. Secure the probe in its position and place the selector switch in position 5. Loosen the locknut of the T1 bottom slug adjustment screw, adjust the slug for maximum meter reading and tighten the locknut while holding the slug in the position of maximum meter reading. Unsolder the jumper.	455 kc., sharp tuning	T1 bottom slug	5	Maximum
2	DISCRIMINATOR SECONDARY—With the RF probe placed as in step 1 adjust the top slug of T1 for exactly zero meter reading (selector switch in position +4 or -4).	455 kc., sharp tuning	T1 top slug	+4 or -4	Zero
3	455 KC. I.F. COIL L16—Place the RF probe near the input to the 455 kc. I.F. filter (see illustration). Couple the signal loosely so that an increase of signal strength will produce a linear increase in meter reading (switch in position 2). Secure the probe in position to keep the input at a constant level. Adjust L16 for a maximum meter reading with the switch in position 2.	455 kc., sharp tuning	L16	2	Maximum
4	455 KC. I.F. COIL L15—Couple the signal to the I.F. filter so as to obtain a maximum reading of approximately 5 ua. with the selector switch in position 1. Adjust L15 for a maximum reading.	455 kc., broad tuning	L15	1	Maximum
5	455 KC. I.F. COIL L14—Use the same conditions as in step 4. Adjust L14 for a maximum meter reading. Place the test set ON-OFF switch in the OFF position and remove the RF probe.	455 kc., sharp tuning	L14	1	Maximum
6	12 MC. I.F. COILS L13, L12 and L11—Set up the Model 80 signal generator (or equivalent) as described below the illustration. After adjusting the signal generator set the test set selector switch to position 1 or 2 and couple the generator output to the grid (pin 1) of V104. The signal must be coupled loosely so that an increase of signal strength produces a linear increase in meter reading (position 1 or 2). Adjust L13, L12 and L11 for a maximum meter reading with the switch in position 4.	12 mc., sharp tuning	L13, L12 and L11	1 or 2	Maximum
7	12 MC. I.F. COILS L10, L9 and L8—Follow the same procedure as in step 6 except couple the signal to the grid (pin 6) of V103 and adjust L10, L9 and L8.	12 mc., sharp tuning	L10, L9 and L8	1 or 2	Maximum
8	FIRST OSCILLATOR COIL L5—Uncouple the signal generator. Position the ceramic trimmer, C110, so that the screwdriver adjustment slot is parallel with the length of the receiver chassis (see illustration). Adjust coil L5 for a maximum meter reading with the selector switch in position 6. On two-frequency receivers be sure that the F1-F2 switch on the control head is in the F1 position while adjusting L5. Then repeat the procedure with the switch in the F2 position while adjusting trimmer C204 and coil L201.	Receiver crystal frequency, sharp tuning	L5	6	Maximum
9	MULTIPLIER COILS L7 and L6—The signal generator must be set for the exact carrier frequency to be received. To do this follow the procedure outlined below the illustration except select the carrier frequency instead of 12 mc. and couple the signal to pin 6 of V103 instead of pin 7, V105. With the generator output coupled loosely to pin 6, V103, adjust L7 and L6 for maximum meter reading (position 1 or 2).	Carrier frequency, sharp tuning	L7, L6	1 or 2	Maximum
10	RF COILS L4, L3 and L2—Keep the signal generator set for the carrier frequency as in step 9. Couple the signal loosely to the grid (pin 1) of V101. Adjust L4, L3 and L2 for maximum reading (position 1 or 2).	Carrier freq., sharp tuning	L4, L3 and L2	1 or 2	Maximum
11	ANTENNA COIL L1—Connect the signal generator output to the antenna receptacle on the receiver chassis. Use a 6 db, 50 ohm, attenuation pad between the generator and the receiver input. Adjust L1 for maximum reading.	Carrier freq., sharp tuning	L1	1 or 2	Maximum
12	FREQUENCY CHECK—Transmit the carrier frequency from the transmitter which this receiver is normally intended to receive. A zero meter reading indicates that the receiver is on frequency. Adjust trimmer C110 to obtain a zero meter reading. Check the final setting by rotating C110 back and forth while observing the meter. The reading should go above and below the zero point as the trimmer is rotated. Set C110 for exactly zero meter reading. On 2-frequency model set switch to F2 position and adjust C204 for zero meter reading.	Carrier freq., sharp tuning	C110	+4 or -4	Zero
13	IGNITION NOISE ADJUSTMENT—Install the receiver in the vehicle. Start the vehicle engine and allow it to run while making the adjustments. Turn the receiver ON and allow it to warm up for five minutes. Radiate a carrier frequency signal from a transmitter, signal generator or test set (see test set instruction manual). The signal should be just strong enough to produce quieting (20 to 30 db). Turn VOLUME control on control head to normal usable level. Plug the test set metering cable into the METER receptacle on the receiver. Set the selector switch to position 2 and note the meter reading. Adjust coil L14 very slightly to reduce audible ignition noise. DO NOT reduce the meter reading more than one-half microampere.	Carrier freq., slight adj.	L14	2	Reduce audible noise

STAGE MEASUREMENTS

APPROX. MICROVOLT INPUT	INPUT TO	FREQ. IN MC.	METER POSITION	METER READING OR DB.
Noise	Antenna	-	1	-0.1 to -1
Noise	Antenna	-	2	-18 to -40
Noise	Antenna	-	4	*0
Noise	Antenna	-	5	-12 to -16
Noise	Antenna	-	6	-12 to -40
0.5 or less	Antenna	F_c	DB Meter	20 db. (quieting)
6.0	Antenna	F_c	1	-2
2.5 14.0	Pin 1 of V 101 1st RF	F_c F_c	DB Meter 1	20 db. (quieting) -2
3.8 30.0	Pin 1 of V 103 1st Mixer	12.0 12.0	DB Meter 1	20 db. (quieting) -2
5.0 150	Pin 1 of V 104 1st IF	12.0 12.0	DB Meter 1	20 db. (quieting) -2
5000	Filter	.455	1	-5
2000	Pin 1 of V 106 2nd IF-1	.455	1	-5
150,000	Pin 1 of V 107 2nd IF-2	.455	1	-5

*A meter reading of up to ±1 ua of zero is allowable without any degradation.

NOTE

A Model T1034A Signal Generator (or equivalent) with output cable should be used when taking readings on V101, V103, and V104. A Model 65B Signal Generator with a 30 ohm terminated output cable was used when taking all other readings.

FIGURE 6

STUDENT NOTES

STUDENT NOTES

national
MOTOROLA
RADIO COMMUNICATIONS
service

A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON MA-6
MAINTENANCE

Transmitter Servicing

MOTOROLA TRAINING INSTITUTE

A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON MA-6
MAINTENANCE

Transmitter Servicing

—one of a series of lessons on two-way FM communications—

MOTOROLA TRAINING INSTITUTE
4501 W. AUGUSTA BLVD., CHICAGO 51, ILLINOIS
APPROVED BY THE STATE OF ILLINOIS
DEPT. OF REGISTRATION AND EDUCATION

PREFACE

This is one lesson of a complete Motorola Home-Study Course which presents to the Service Technician both the principles of operation and the maintenance of two-way FM radio systems. The program covers mobile, portable and base station equipment, including the latest transistorized units.

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TRANSMITTER SERVICING

Lesson MA-6

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NOTICE

Diagrams and figures referenced in text are "fold-outs" in back of each lesson, for use while studying. The Examinations are also there.

One Business Radio Service user is the company specializing in tire service. Large wheels on modern trucks and farm equipment need special handling tools. With radio, firms so equipped are able to provide special service.

TRANSMITTER SERVICING

Lesson MA-6

Introduction

In this lesson we shall discuss various techniques for servicing FM transmitters used in two-way communications. We shall proceed in the following order: (1) identification of a fault, pinpointing it to a particular section of the transmitter, (2) location of the specific trouble, and (3) correction of the trouble.

We shall be using the high-band transmitter shown in figures 1 and 2, but the trouble-shooting techniques applied to this unit will work equally well with other transmitters, particularly with the low-band units. Toward the end of the lesson, we shall discuss problems which apply only to certain specialized equipment, such as 450-mc transmitters.

Determining the Exact Trouble, Using the Motorola Test Set Only

When using the Motorola test set only, the serviceman will follow test procedures which are different from those he would use if he had more test equipment available. To start, let's assume that he has only the Motorola test set, and that the fault is definitely in the transmitter--both the antenna system and the power supply are normal.

RF Output

The first step when trouble shooting any transmitter is to observe the reading in the PA position of the test set. If this reading is high, the HI-LO switch must be placed in the LO position. Now observe the readings of test set positions 3, 4, 5, and 6 to get an over-all idea of the transmitter operation. If an intelligent appraisal is to be made, these readings must be compared both with the recommended values and with the values previously recorded for the transmitter, when it was operating normally.

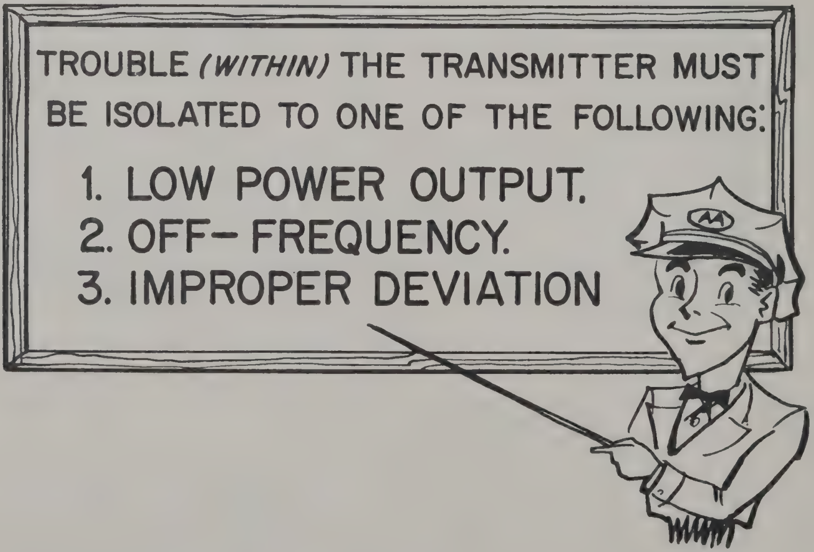
The meter readings with the test set in positions 3, 4, 5, and 6 are used to check the preceding stages. Thus, if the reading at position 3 is normal, we know that the RF level at this point is normal. That is, the oscillator, modulator, buffer-doubler, and tripler input circuit are all operating as they should. (The frequency may be incorrect, but at this point in our procedure we are interested only in the amount of RF.)

The reading at position 4 checks the operation of the tripler stage and the input to the second doubler. If the reading at 4 is normal, try position 5. If the reading is still normal, proceed to position 6.

How do these meter readings help isolate the trouble? Let us suppose that the readings at positions 3 and 4 are normal, but that the readings at 5 and 6 are low. This tells us that the trouble is in either the second doubler or the input of the driver stage. The logical procedure is to try new tubes in these stages and to check the readings again. If normal readings are now obtained, merely touchup the alignment and your unit will be ready for use. If the readings are still low, however, more detailed trouble shooting will be required in these stages.

As another example, let us assume that all the readings are zero, or at least very low. (The reading at position 6 is never zero so long as the bias supply is applied to the grid circuit of the PA stage.) This means that the trouble is in one of the first three stages (oscillator, modulator or buffer) or that it is in the input to the tripler stage. Again the logical procedure is to try new tubes in these stages. (Try another crystal in the oscillator, too, if a suitable one is available.) If this procedure fails to correct the condition, further trouble shooting will be required.

When the reading at all positions (3 through 6) are normal, the next problem facing the technician is to determine if there is an RF output; and if so, to determine its approximate power.


TROUBLE *(WITHIN)* THE TRANSMITTER MUST BE ISOLATED TO ONE OF THE FOLLOWING:
1. LOW POWER OUTPUT.
2. OFF-FREQUENCY.
3. IMPROPER DEVIATION

In Trouble Shooting the Transmitter Be Sure to Identify the Specific Trouble to be Corrected.

The meter positions provided in high-band and low-band transmitters do not show RF power output. The reading at position PA is an indication of the DC plate current only and is no guarantee of RF power. Only when the complete alignment procedure of the final tank, coupling and antenna circuits are followed, with normal results, can we be reasonably sure that the reading at the PA position shows the presence of RF power in the antenna. The test set responds to RF signals when used as a field strength meter, but it does not indicate the frequency or the amount of output.

Measuring Power Output

As we have just seen, measuring the power output of the transmitter becomes a problem when all the serviceman has available is the Motorola test set. If he is to provide quick and accurate service, he should be equipped with some means of actually measuring the RF output at the transmitter. Either a wattmeter or the Motorola dummy antenna (used with the test set) will serve this purpose.

Several types of wattmeters are available. Any type will suffice for determining the power output of the transmitter as long as it is reasonably accurate at the frequency involved. Using the Motorola dummy antenna, relative readings can be taken on the test set and the power can be accurately determined by means of the charts supplied. These instruments are easy to use when it is desired to measure the carrier power quickly. From the standpoint of isolating the trouble, the serviceman, as soon as he knows that the power output is normal, can concentrate on the operating frequency, the modulation, or any other faults that might exist within the transmitter.[1]

Even though the RF power output of a transmitter is known to be relatively normal, the transmitter itself may not be operating normally because (1) the carrier frequency is not on channel, or (2) the modulation is nonexistent, or at least very low.

Operating Frequency

The possibility that the carrier is off channel can be detected by means of a monitor receiver of known calibration, or by means of a frequency measuring device. If neither of these is available, the serviceman will be unable to determine the operating frequency of the transmitter.

Modulation

Metering facilities are not provided in the transmitter for measuring either the modulation or the audio input to the modulator. The newer TU546 test set, however, allows the audio voltage to be measured at the microphone, and this tells the serviceman that there is audio in the transmitter.

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1. See Test Methods, section 2, pages 29-31.

Additional equipment is required in order to check modulation.

Isolating the Trouble -- Monitor Receiver

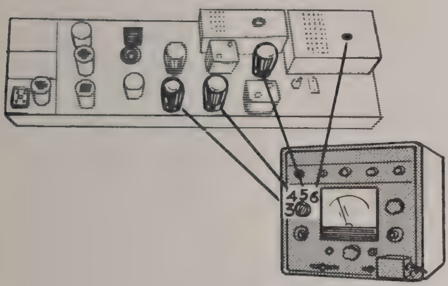
We have just seen how a fault is isolated within a transmitter when using only a Motorola test set. A monitor receiver can also be used for making a quick check if the technician has one available. (We must assume that the monitor receiver picks up signals from other transmitters within the system and reproduces them with normal clarity.) The first step is to open the receiver squelch so that some noise is heard. The transmitter is then keyed and any noise quieting in the receiver noted. If there is some quieting, a carrier is present, although it may be weak or slightly off channel. The off channel factor is immediately checked by observing the test set reading at the discriminator secondary--it should be near zero. Although it is not advisable to adjust the transmitter frequency according to the reading on the receiver discriminator, this reading provides a good check on the approximate carrier frequency.

The monitor receiver also provides a check on any modulation taking place in the transmitter. If the carrier provides a reasonable amount of quieting in the receiver and if the carrier is reasonably close to the correct frequency, the receiver output will indicate the presence of modulation, whether weak, normal, or overdeviated. The receiver, however, will not give an accurate indication of the modulation if the carrier is too far off frequency. Again, the monitor receiver is not to be used to adjust the modulation of the transmitter; it merely gives the serviceman a relative idea of what is taking place. It enables him to quickly ascertain if there is trouble within the transmitter, and if it is one of the areas checked.

We have learned thus far how to isolate the trouble in a transmitter, pinpointing it to some particular stage or section. Once this has been done--and if the fault is not readily corrected by some simple adjustment or a replacement tube--it will be necessary to further analyze the faulty stages of the transmitter. In many instances the transmitter must be removed and placed on the test bench for this more complete analysis.

Trouble Shooting the Oscillator

Voltage and resistance readings, such as those shown in figure 1 for the 10-watt transmitter, are helpful in locating a defective component. This particular transmitter also provides for monitoring the oscillator activity (test meter position 2). The minimum reading is 10, but it will be higher than this in most cases. If the reading should drop below 10, however, the oscillator should be watched both for activity and for frequency.



Test Set Measurements Help to Quickly Isolate "Low Output" Trouble to a Specific Stage of the Transmitter.

While the test-set reading at position 2 can be taken as an accurate indication of the amount of oscillator activity, it does not tell us how well the plate circuit of the oscillator operates, nor does it tell anything about the signal applied to the modulator or to the buffer-doubler. This information can best be obtained by measuring the voltage at the buffer grid, which is a good indication of the signal level. In figure 1, the voltage at the buffer grid is 2.5 volts negative. This serves, then, as an indication of the RF level, which is the output from the oscillator-modulator section. A VTVM equipped with an RF probe will also indicate the presence of RF. The probe may be used at the plate circuit of the oscillator and at the grids of the modulator and buff-doubler stages to determine the RF level at these points.

Low RF output from the oscillator may be caused by low supply voltages resulting from resistance changes in the plate and screen dropping resistors, open or leaky capacitors, a weak tube, or a poor crystal. In most instances a voltage and resistance check of the circuit and its components will reveal the defect, but occasionally it may be necessary to substitute new units and compare the results.

The Modulator

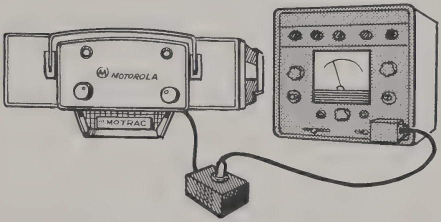
The modulator is basically a low-gain RF amplifier stage in which provision is made to phase modulate the RF signal in the output. The DC grid voltage is zero with respect to ground, and bias is supplied by a cathode resistor. Trouble shooting is accomplished by means of (1) voltage checks, (2) resistance checks, and (3) tests performed on the individual components.

Modulation deviation and linearity is determined to a considerable extent by the operation of the stage. It is therefore important to keep the voltages near their nominal values.

Looking at the schematic, we see an electrolytic bypass capacitor at the cathode. Its bypass quality may be poor without seriously changing the DC operating voltages. At the same time, however, the modulation characteristics of the stage could be poor; the modulation may be weak as well as distorted.

The Buffer-Doubler

The buffer-doubler is basically an RF amplifier which provides an output at twice the frequency of the input signal. The grid voltage is due both to the oscillator output and to the signal from the modulator. To provide good modulation linearity and a stable carrier frequency, the stage is operated with Class B_2 bias rather than Class C. (Class B_2 indicates operation near cut-off, with the grid driven positive by the signal.) Before performing any detailed trouble shooting, the serviceman should make sure that the grid drive (voltage) is correct.



The Motorola Test Set and Dummy Antenna may be Used to Measure Transmitter Power Output.

Figure 1 shows no metering facility for the buffer-doubler, but the grid drive is checked by reading the negative grid voltage, which should be at least 2.5 volts for this particular transmitter. This grid voltage controls, to some extent, the voltages at the other tube elements. The action is as follows: The grid bias voltage limits the amount of plate current, and the plate current establishes voltage drops across the various resistors in the circuit. If the plate current increases, the voltage across the plate dropping resistor (R1) also increases, causing a lower potential at the plate. At the same time, the increased plate current through the cathode resistor increases the cathode voltage.

With the proper signal applied to its grid, the operation of the buffer-doubler stage may be determined by the reading at the grid of the following tripler stage (position 3). The maximum voltage at position 3 will be obtained only when the interstage transformer is peaked. This transformer has a tuned primary and a tuned secondary; as either is adjusted to resonance, a sharp maximum reading should result. If either the primary or the secondary fails to show a satisfactory peak, the circuits will not be properly tuned.

Tripler, Doubler and Doubler-Driver

These three stages all operate in much the same manner. As Class C amplifiers and frequency multipliers, they increase both the power and the frequency of the RF signal. Trouble shooting procedures for all three stages are essentially the same as that described for the buffer-doubler.

The RF output of each stage depends primarily upon the grid drive voltage. Therefore, the input signal to any stage must be normal before any further checks are made. The RF output of each stage is conveniently measured at the grid of the following stage. Each stage provides some reserve drive to the next stage. That is, the grid drive is more than the minimum amount needed to produce the required output. Thus, while the readings given in figure 1 are satisfactory, it is desirable to have more than this nominal amount in order to counteract the normal decreases that occur as the equipment ages.

These three multiplier stages incorporate pentode type tubes because they offer high gain with minimum drive. Screen voltages must be correct if full power output is to be realized. The screen voltage greatly affects the amount of plate current, and in a Class C amplifier or multiplier the power output is generally a direct function of the amount of plate current and the amount of grid drive.

It should never be necessary to make any change in the circuitry or in the value of a component in order to obtain correct drive voltages. If the recommended readings are not obtained, look for a defective component. Neither should interstage coupling be changed. Occasionally it would appear that the degree of coupling (between doubler-driver and PA, for example) could be changed by altering the relative position of the primary and secondary winding. This must not be done, however, for although it may seem that the amount of grid drive could thus be increased, this is not always the case.

The driver output (or the input to the PA) may increase in undesirable harmonics, but not in desired signal. The spurious emission may also exceed the maximum allowed. (The 450-mc transmitter is an exception to this rule, however. Here the interstage coupling is variable and must be adjusted according to the recommended procedure.)

Power Amplifier Problems

The various adjustments and alignments required in the PA stage make it one of the most critical sections of the transmitter. It is subject to more damages as a result of misalignment because of its high power level and its tubes are the most expensive in the transmitter. It is thus advisable to minimize tube replacement by making sure that they are always operating properly.

Plate current is controlled by the grid voltage, the screen voltage, the plate voltage and the plate tank, also by the antenna loading adjustments. To prevent the plate current from becoming excessive (in case the grid drive should fail), fixed bias is applied to the grid at all times. Moreover, a "High-Low" switch is usually incorporated in the screen grid circuit.

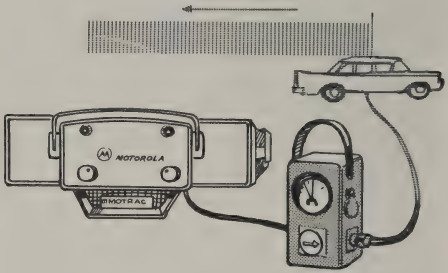
This switch permits lowering the screen voltage by inserting a higher resistance in the screen circuit when the plate circuit is not properly tuned. If the final stage is not operating properly, the switch is immediately placed at "Low" and left in that position until servicing and tuning are completed.

When the grid drive is normal, the stage is biased Class C. Unless the plate circuit is tuned to resonance, however, the current may still be too high; hence, the switch is left at "Low" until the plate tank is adjusted to resonance.

If the PA grid drive fails, the fixed bias will keep the plate current from rising beyond the safe limits for the tube. With no RF in the plate circuit, the tuning of the plate tank has no effect on the plate current--and there can be no coupling to the antenna if there is no RF present. With no RF power present, coupling adjustments will have no affect on the plate current.

Trouble is quickly pinpointed to either the grid circuit or the plate circuit by observing the meter readings at position 6 for the grid, and at the PA position for the plate. It can also be isolated by observing the peaks when the circuits are tuned through resonance. (When the final is loaded by the antenna, the plate current peak will be very broad.)

Voltage readings for the final stage will help to pinpoint any trouble to the defective portion of the circuit. Resistance readings are also very helpful, especially in locating resistors that have changed value.



If a Thruline Output Meter is Used, the Transmission Line Should Terminate into the Antenna.

Reduced RF output (assuming that the input is normal) may be caused by a weak tube, low supply voltages, improper tuning, a defective component, or any combination of these factors. Each possibility should be checked thoroughly in any logical trouble shooting procedure. If the grid drive is normal, the tube may be replaced by one known to be good and the results compared. The final tube will often show a slight "glow" around the glass envelope. A slight glow may be normal and does not necessarily indicate a defective tube or excessive current. In low-power transmitters (such as the 10-watt unit), the PA tube is less apt to show this glow than when this same tube is operated with higher voltages to produce power outputs of 25 watts or more. If the tube becomes gassy (or "soft," as it is often called), there will be a glow around its electrodes and this glow will extend over the greater portion of the tube. This will generally indicate a defective tube (low power output) and the tube should be replaced. Operating a tube beyond the recommended values of plate and screen current will often make it prematurely soft and shorten its life.

The Audio Stages

The audio stages in the transmitter of figure 1 are the audio amplifier and the clipper. Where transistorized microphones are used, the transistor amplifier must be considered as part of the audio section of the transmitter, even though the amplifier itself is mounted in the microphone housing.

Misadjustment of the "instantaneous deviation control" (IDC) can produce bad effects, both in the operation of the system and in the interference produced in other channels. Because of the great importance of this circuit, the serviceman must be careful to establish its proper operation and maintain a proper adjustment of the control (R130) at all times.

Once the input signal reaches a certain predetermined level, the output voltage no longer increases. By driving the diodes in the clipper stage to maximum plate current, the output voltage is limited in amplitude; stronger audio voltages cannot produce higher voltages from the clipper. In most transmitters the maximum input level without causing clipping is 0.18 volt at the grid of the amplifier (0.25-volt signal at the input if the tap at position 1 is used). Before proceeding to adjust the IDC control for the correct amount of deviation, the modulation sensitivity must be correct. That is, with 0.25 volt applied to the input, the peaks of the signal reaching the 6AL5 should be at the point of clipping.

To check the modulation sensitivity, place a VTVM between terminal 2 or 7 of the 6AL5 socket and ground, using the lowest practical DC scale. The standard test signal for the audio section of the transmitter is 1000 cps, and this signal should be applied to the transmitter input. As the input is increased and approaches 0.25 volt, a slight wiggle will be observed on the meter, indicating that the peaks of the signal are being clipped. If the input is further increased, the meter reading will decrease.

The point at which the meter shows the slight wiggle is the clip level. While this is 0.25 volt for most transmitters, the service manual should always be consulted for verification; some transmitters use different values for their modulation sensitivity.

Microphones sometimes have outputs of 0.18 volt. When this is the case, the input coupling capacitor is connected to the alternate tap, allowing the full voltage to reach the audio amplifier input.

Measuring Deviation

In order to determine the amount of deviation, it is necessary to use a suitable deviation meter. With a 1000-cps sinewave signal at the input, the deviation should be set to a full 15 kc (or to 5 kc, when that value applies). When the input is not a true sinewave (voice modulation, for example), the deviation is adjusted for an indication of about 12 kc, using a sustained voice tone such as Ah-h-h-h-h--. Then, when we speak into the mike, the peaks should reach 10 kc on the deviation meter.

The scope, when used in conjunction with a deviation meter, becomes a most accurate indicator of deviation. It must first be calibrated, however. This can readily be accomplished with a deviation meter, using a signal which is below the clip level. The 1000-cps signal is applied to the audio section so that the deviation is 10 kc on the meter. The scope vertical gain is then adjusted for a convenient deflection, such as 10 squares, on the scope screening. (The scope controls must now remain in the same setting for the rest of the check.)

Since the deviation is increased by increasing the input voltage, the IDC circuit will eventually start clipping the amplitude, but the indications of the deviation meter and the scope may not agree. While the scope will show the true peak deviations, the deviation meter responds to the average deviation; its scale is marked according to the corresponding peak value rather than the average. This meter reading is accurate only so long as the input signal is a sinewave, and not clipped. As soon as the signal deviates from the sinewave, however, the peak will no longer have the same relative value with respect to the average value, and the deviation reading may not represent the true peak.

This does not mean that the deviation meter is not satisfactory for setting the deviation of the transmitter. The difference or error is very low for deviation values through 15 kc, and the error becomes significant only when the IDC circuit goes into full limiting.

The Motorola Monitor Measures Both Frequency and Deviation.

The foregoing discussion was based on an input signal of 1000 cps. Where the signal frequency is lower and clipping occurs, the average energy will be less in comparison to the peak than for the 1000-cps input. Thus, where a low-frequency signal is used, the deviation indicated by the meter for a clipped condition is likely to be lower than that recorded on the scope.

From the preceding discussions, we see that there are several factors that must be taken into consideration when trouble shooting the audio section of the transmitter. First and foremost is modulation sensitivity. If the modulation sensitivity is low, it should be corrected in the amplifier section rather than by advancing the IDC control. If the IDC control is advanced, there may not be an immediate change in the operation of the transmitter. If the control is advanced, however, because the amplifier gain is low, and then later the amplifier gain is restored to normal by replacing a weak tube, the IDC control must again be adjusted for correct deviation.

Another example of improper service procedure has to do with a weak mike. The serviceman finds that the modulation of the transmitter is weak and, rather than doing a little trouble shooting and finding out the reason, he merely advances the IDC control. This means that the audio input may never reach the clip level, and there may be no IDC action. Moreover, the weak mike eventually becomes inoperative and it must be replaced. The serviceman will be guilty of an error of omission if he fails to recheck the deviation. The output is good and loud, he reasons, so why worry about the amount of deviation! The deviation is now beyond the bandwidth of the receivers in the system and the Permakay filter in the receiver prevents some of the sideband energy from getting through to the discriminator. This results in a distorted output and a consequent sacrifice in quality. The excessive deviation also produces a lot of sideband energy which falls in the adjacent channels and interferes with systems operating within these channels.

If the modulation sensitivity is not up to par, either the amplification of the audio stage is low or the clipper is not working properly. A further check of these stages should disclose the specific trouble.[2]

Transmitter Alignment

The alignment procedure of any transmitter must include three steps: (1) the RF circuits must be adjusted so that the correct amount of power is delivered to the antenna, (2) the transmitter must be placed on the proper frequency, and (3) the modulation (deviation) must be correct.

To obtain the proper RF signal at the antenna, all of the circuits between the oscillator and

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2. See Test Methods, section 2, pages 53, 54 and 57, also section 3, pages 34-36; also see "Let's Measure Modulation," reference M-6.

antenna must be tuned to their correct frequency and the coupling must be properly adjusted between the PA stage and the antenna. The circuits from oscillator to PA are tuned for maximum indications at the grids of the following stages. The PA plate tank is adjusted for minimum plate current. After the plate tank is tuned, the antenna coupling circuits are adjusted to obtain the proper amount of RF in the antenna (determined by the amount of plate current).

The service manual lists certain normal readings for each stage of the transmitter. Unless these readings are obtained, it is not advisable to proceed with the rest of the alignment, for the proper operation of each stage depends upon the grid drive from the preceding stage.

The actual power output of the transmitter cannot be accurately determined merely by knowing the amount of plate current in the PA stage. Power output is best measured by means of an accurate wattmeter connected between the transmitter and antenna. Instead of the antenna, a dummy load of the proper impedance may be used with the wattmeter. This wattmeter should read both forward and reverse power, particularly if it is terminated into the regular antenna system. A transmitter may fail to load properly because of a defective antenna system, and this is readily detected by means of the forward-reverse power readings on the wattmeter.[3]

This Portable Motorola Meter Accurately Measures the Frequency and Deviation of Transmitters, between 20 and 100 MC.

The frequency of the transmitter is determined basically at the oscillator. An adjustment at the oscillator stage provides for placing the transmitter at the correct frequency. By monitoring the transmitter output with a frequency meter the oscillator can be warped until the transmitter frequency is correct. The reliability of this procedure is limited only by the accuracy of the frequency-measuring device.[4]

Deviation measurement requires the use of a special meter to monitor the transmitter output during modulation.

Besides the general alignment procedure discussed in this lesson, specific recommendations for the individual transmitter must be followed in detail, particularly in the loading procedure for the

3. See Test Methods, section 3, pages 17-25.
4. See Test Methods, section 2, pages 32-39 and section 3, pages 10-15.

final stage. Unless the loading is correct, the final tubes may overheat and fail prematurely. Recommended procedures must be followed, also, in order to provide the specified amount of RF power output from the transmitter, with minimum harmonic radiation.

Parasitics

Parasitics, when encountered in transmitters, are usually recognized by the radiation of abnormal signals, signals which are not normal for the transmitter. The reading at position 6 (the final grid) is likely to be abnormally high and the tuning of the circuits erratic. The power output is usually low when measured on a wattmeter, and erratic when the final is loaded by the antenna or by a dummy load.

Further evidence of the existence of parasitics is the overheating of components, particularly the parasitic suppressors! Severe parasitic oscillations may even cause the suppressors to burn up.

One method of determining the presence of parasitic oscillations is to remove the drive from the final stage momentarily, while observing the behavior of the final grid and plate circuits. If the oscillations are strong, the wattmeter may indicate some power output.

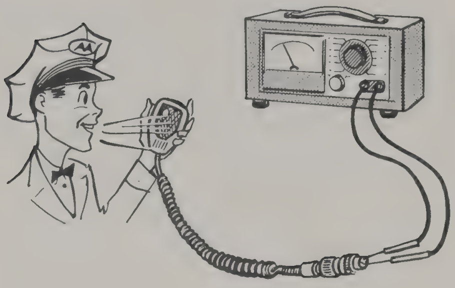
The most common causes of parasitic oscillations are defective bypass capacitors, and stages improperly neutralized. (It is essential that the neutralization procedure recommended by the manufacturer be followed in every detail.) Another likely source of parasitics is the final amplifier tube itself.

450-MC Transmitters

Before discussing troubles which may be associated with 450-mc transmitters, it is necessary to say something about circuit variations which may alter the trouble shooting and alignment procedures. This is the case where a metering circuit has been provided for measuring the power output. The meter does not give a quantitative indication of the power, but it does show peaks. It provides a means of tuning the final stage and loading the transmitter into the antenna the same as if a wattmeter were used.

Some 450-mc transmitters have a modulation sensitivity of 0.1 volt, which means that only this amount of voltage is required at the input terminals in order to cause the necessary deviation.

Another unique feature (in some 450-mc Motorola transmitters) is the use of variable coupling between the driver and final stages. Normally this coupling is fixed in



Establishing the Amount of Mike Voltage--As Measured on a Sensitive AC Voltmeter--is Helpful in Diagnosing Modulation Problems.

the transmitter, but it is desirable for it to be variable in certain instances, to obtain optimum operation of the final stages.

One of the most common complaints in connection with 450-mc transmitters concerns low power output. This is sometimes caused by the 2C39 tubes used for the final stages of some high-frequency transmitters.

When the power output is low, the first thing to check is the drive to the final and to the preceding stages. There is little reserve drive in the final stages; unless the driving voltages are up to par, the final cannot develop full power output. The final stage in Motorola transmitters is driven by a tripler stage, and the drive to this tripler is very critical. It is just as important to avoid overcoupling in this stage as it is to secure sufficient coupling. The coupling to the tripler grid is thus made variable and it must be properly adjusted by the serviceman.

The tripler coupling to the final stage can usually be set at maximum, provided no limit is specified in the alignment procedure. (This will vary from one model to another.) With the input to the final stage known to be satisfactory, the tuning and antenna loading procedures are checked. Then, if it is still impossible to obtain normal power output, a new tube should be tried in the final. The tripler-driver and the final use the same type tube in Motorola 450-mc transmitters, and these tubes can be interchanged for the purpose of comparing the power output. It is common for the final tube to operate satisfactorily in the driver stage even though it may not give full power output in the final stage.

Low power output may also be caused by low supply voltage, either filament or plate, and this possibility must never be overlooked. Another possible source of trouble is the contacts of tube filaments. Filament power is applied through these spring connectors, so they must make good contact. Poor contact causes loss of power and overheating. Low power output may be traced to defective bypass capacitors in the grid and plate circuits. These capacitors often make use of mica sheets which are held to the chassis by screws. If these screws should become loose, the capacitance is reduced and the power output decreases. The remedy is to simply tighten the screws. The ground return of the various coupling loops may be making poor contact with the chassis because of the accumulation of dirt. This also is a possible cause of low power. The remedy is to clean the ground contact.

250-Watt Transmitters

Quarter-kilowatt transmitters use an ordinary 30-60 watt transmitter as the driving section for the high-powered final. In most instances, the problems encountered are due to misaligned final stages.

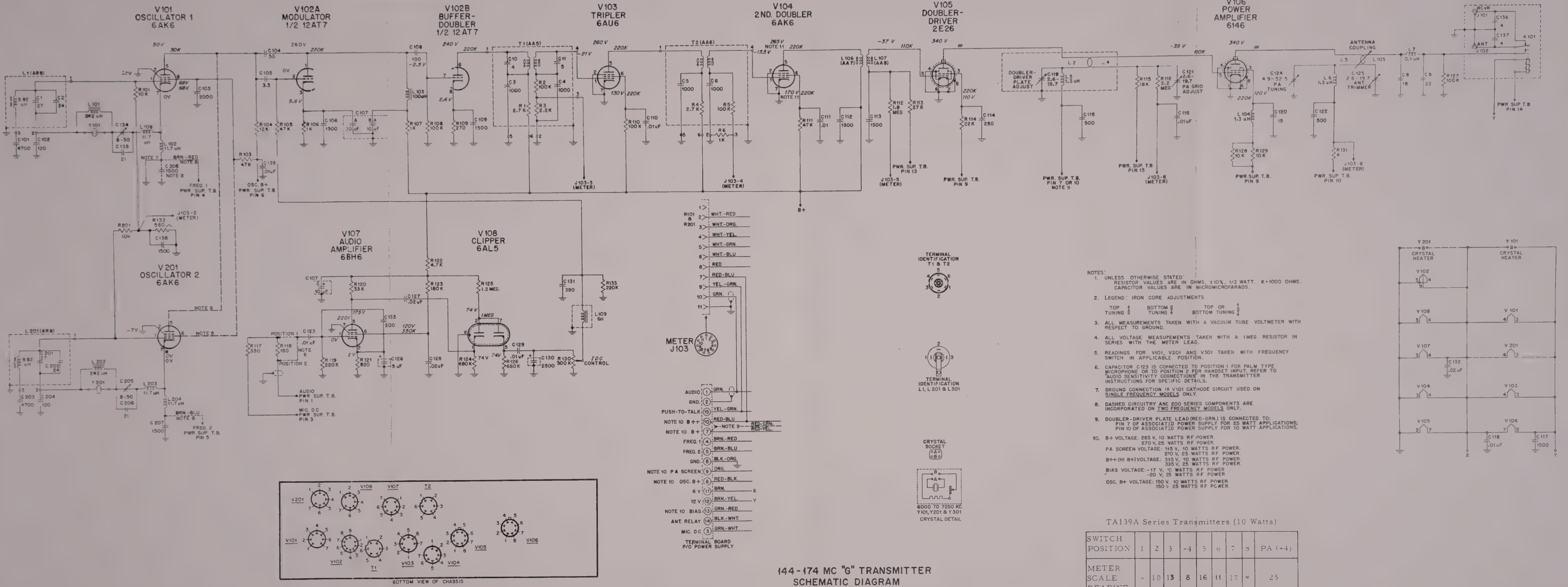
Neutralization is one of the most important factors in the tuning of 250-watt finals. This is required with both low-band and high-band units but not with the 450-mc transmitter, which is fixed-neutralized. No particular alignment, adjustment, or neutralization procedure is applicable for all models of 250-watt transmitters; the step-by-step instructions provided by the manufacturer must be consulted for each model.

The antenna change-over relay may sometimes become a source of trouble, especially when its contacts become pitted or charred because of the higher RF power handled.

In working with transmitters, particularly high-powered units, the serviceman must exercise unusual care to avoid coming into contact with "hot" circuits. The high-voltage warning must be observed at all times. It is well for the serviceman to be thoroughly familiar with normal safety measures and first aid procedures.

STUDENT NOTES

STUDENT NOTES



NOTES:

1. UNLESS OTHERWISE STATED:
   RESISTOR VALUES ARE IN OHMS, ±10%, 1/2 WATT. K=1000 OHMS.
   CAPACITOR VALUES ARE IN MICROMICROFARADS.
2. LEGEND: IRON CORE ADJUSTMENTS
   TOP TUNING ↑ BOTTOM TUNING ↓ TOP OR BOTTOM TUNING ↕
3. ALL MEASUREMENTS TAKEN WITH A VACUUM TUBE VOLTMETER WITH RESPECT TO GROUND.
4. ALL VOLTAGE MEASUPEMENTS TAKEN WITH A 1MEG RESISTOR IN SERIES WITH THE METER LEAD.
5. READINGS FOR V101, V201 AND V301 TAKEN WITH FREQUENCY SWITCH IN APPLICABLE POSITION.
6. CAPACITOR C123 IS CONNECTED TO POSITION 1 FOR PALM TYPE MICROPHONE OR TO POSITION 2 FOR HANDSET INPUT. REFER TO "AUDIO SENSITIVITY CONNECTIONS" IN THE TRANSMITTER INSTRUCTIONS FOR SPECIFIC DETAILS.
7. GROUND CONNECTION IN V101 CATHODE CIRCUIT USED ON SINGLE FREQUENCY MODELS ONLY.
8. DASHED CIRCUITRY AND 200 SERIES COMPONENTS ARE INCORPORATED ON TWO FREQUENCY MODELS ONLY.
9. DOUBLER-DRIVER PLATE LEAD (RED-GRN.) IS CONNECTED TO:
   PIN 7 OF ASSOCIATED POWER SUPPLY FOR 25 WATT APPLICATIONS;
   PIN 10 OF ASSOCIATED POWER SUPPLY FOR 10 WATT APPLICATIONS.
10. B+ VOLTAGE: 285 V, 10 WATTS RF POWER.
    270 V, 25 WATTS RF POWER.
    PA SCREEN VOLTAGE: 145 V, 10 WATTS RF POWER.
    270 V, 25 WATTS RF POWER.
    B++ (HI B+) VOLTAGE: 315 V, 10 WATTS RF POWER.
    335 V, 25 WATTS RF POWER.
    BIAS VOLTAGE: -17 V, 10 WATTS RF POWER
    -20 V, 25 WATTS RF POWER
    OSC. B+ VOLTAGE: 150 V. 10 WATTS RF POWER.
    150 V 25 WATTS RF POWER.

TA139A Series Transmitters (10 Watts)

SWITCH POSITION	1	2	3	-4	5	6	7	8	PA (+4)
METER SCALE READING	-	10	13	8	16	11	17	*	25

144-174 MC "G" TRANSMITTER
SCHEMATIC DIAGRAM
FIGURE 1

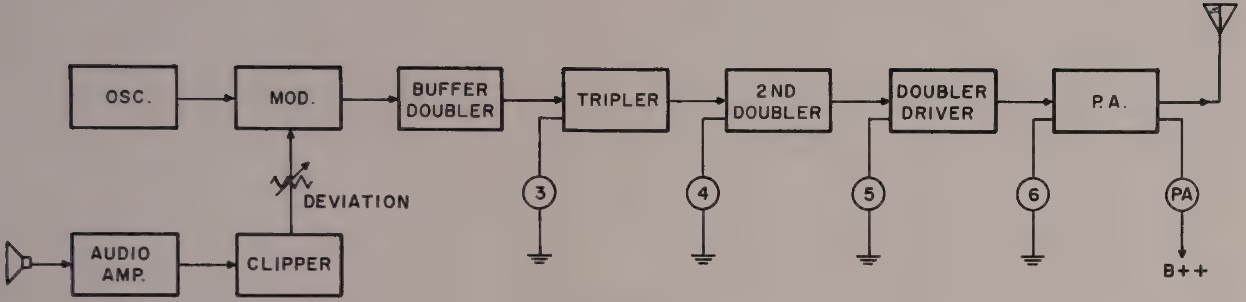
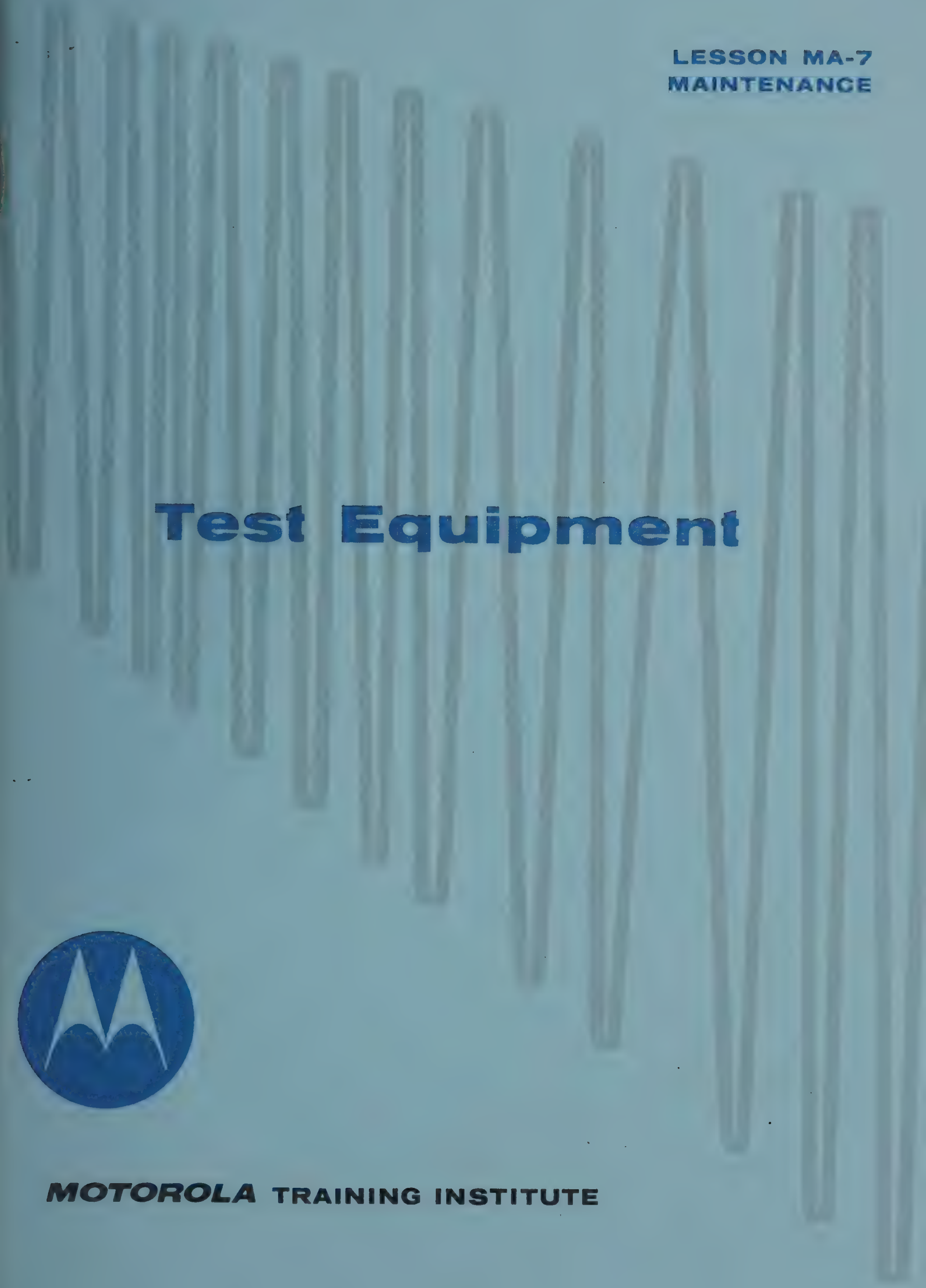

OSC.
MOD.
BUFFER DOUBLER
TRIPLER
2ND DOUBLER
DOUBLER DRIVER
P.A.
AUDIO AMP.
CLIPPER
DEVIATION
3
4
5
6
PA
B++

FIGURE 2

national
MOTOROLA
RADIO COMMUNICATIONS
service

A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON MA-7
MAINTENANCE



Test Equipment

MOTOROLA TRAINING INSTITUTE

A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON MA-7
MAINTENANCE

Test Equipment

—one of a series of lessons on two-way FM communications—

MOTOROLA TRAINING INSTITUTE
4501 W. AUGUSTA BLVD., CHICAGO 51, ILLINOIS
APPROVED BY THE STATE OF ILLINOIS
DEPT. OF REGISTRATION AND EDUCATION

PREFACE

This is one lesson of a complete Motorola Home-Study Course which presents to the Service Technician both the principles of operation and the maintenance of two-way FM radio systems. The program covers mobile, portable and base station equipment, including the latest transistorized units.

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TEST EQUIPMENT

LESSON MA-7

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NOTICE

Diagrams and figures referenced in text are "fold-outs" in back of each lesson, for use while studying. The Examinations are also there.

Building contractors, ranging from plumbers to roofers, find that two-way radio enables continuous management supervision. Workmen's efficiency is also increased by the ability to closely control schedules, vehicles and supplies.

TEST EQUIPMENT

Lesson MA-7

Introduction

In this assignment we shall discuss those pieces of test equipment which are used in servicing two-way FM communications equipment. Our study will include the operation of frequency meters, deviations meters, signal generators and wattmeters, and some thought will be given to the application of the oscilloscope and AC voltmeter.

It will be recalled that the FCC requires frequency and deviation measurements of each transmitter to be taken at least once every six months. The serviceman must therefore be able to use these instruments intelligently. We shall begin our discussion with the frequency meter.

Frequency Meters; Motorola Monitor

It is only fitting that we should start with the Motorola FM Station Monitor. This instrument serves both as a deviation meter and as a frequency meter, but for the moment we will be concerned only with the frequency measuring function.

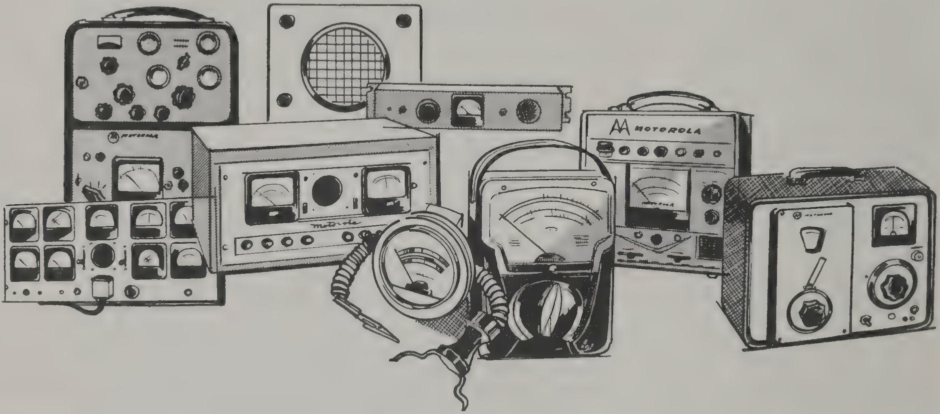
The Motorola FM Station Monitor is available in two models (for high and low bands, respectively) but the principle of operation is the same for either. Thus, while we shall be discussing the use of this instrument for high-band measurements, its use for low-band measurements will follow the same principles.

The first step is to check the 5-mc calibrating crystal oscillator of the instrument against the highly stable signal of station WWV, operated by the Bureau of Standards. A WWV receiver is included for this purpose. Depending upon the location, the WWV signals of 5 and 10 mc or of 10 and 15 mc are used.

Figure 1A shows a block diagram of the arrangement. The WWV receiver is first tuned for station WWV. The 5-mc oscillator is then adjusted to zero beat with WWV. By exercising care in this adjustment, the oscillator can be held to within one or two cycles of 5 mc.

The second step is shown in figure 1B. The WWV receiver is turned off and the 5-mc oscillator switched to the input of the control receiver--which is to be tuned to 150, 155 or 160 mc.

Let's assume that the receiver frequency is 150 mc. The receiver is calibrated at exactly 150 mc by tuning it for zero discriminator output on the 30th harmonic of the 5-mc oscillator. Even with an oscillator variation of a few cycles (multiplied 30 times), the 150-mc receiver will still be within 100 cycles of exact frequency. For all practical purposes, this error is insignificant.



The Proper Test Equipment is Essential to Quick and Intelligent Service of Two-Way Radio Equipment.

Before making any frequency measurements, we must determine the frequency of the crystal which is to be used. This will depend on (1) the frequency of the transmitter to be measured, and (2) the frequency of the control receiver. Let us assume that we wish to measure the frequency of a transmitter operating at 152.5 mc and that our control receiver frequency is 150 mc. The difference frequency between the transmitter (152.5 mc) and the control receiver (150 mc) is 2.5 mc. This is the required crystal oscillator frequency (step 3, figure 1C). Step 4 figure 1C shows the actual measurement of the RF frequency. A crystal of the required frequency (as determined in step 3) is substituted (by means of a switch) for the 5-mc crystal in the oscillator. The signal is then mixed with the carrier frequency being measured, and the output applied to the control receiver. The carrier (assumed to be exactly 152.5 mc) beats against 2.5 mc and the difference is 150 mc, the frequency of the standard receiver. The discriminator output will be zero, indicating that the carrier is at its exact channel frequency.

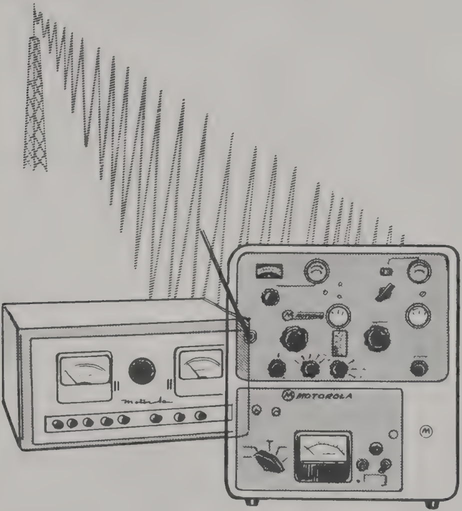
If the RF is not on exact channel frequency, however, the signal input to the control receiver will be off by the same amount, and this will be recorded by the meter. For example, suppose the RF frequency is actually 152.502 mc. When this beats against the 2.5-mc oscillator the difference frequency is 150.002 mc and this signal, when applied to the 150-mc receiver, will produce a difference of 2 kc at the discriminator. The calibrated meter will record a + 2-kc variation.

If the 2.5-mc crystal oscillator is off frequency, there will be an error in the frequency recorded even though the RFis at the exact channel frequency. Thus the accuracy of the measurement depends upon the accuracy of the crystal. Let's see just how much the crystal affects this accuracy. Suppose the crystal has a guaranteed accuracy of .002 per cent. This means that the 2.5-mc oscillator will be within 50 cycles of 2.5 mc (2,500,000 times .00002). Beating this oscillator directly against the RFsignal means that the difference frequency must be within 50 cycles of its proper frequency. Now 50 cycles, as far as 152.5 mc is concerned, represents a variation of only .000033 per cent. Thus the monitor for this particular measurement is extremely accurate. The "improvement" in accuracy from that of the crystal to that of the RF being measured is determined by the ratio of the RF frequency to that of the crystal. Thus 152.5 mc to 2.5 mc represents an improvement of 61 to 1. Where the selected crystal frequency is higher than 2.5 mc, the improvement factor will be correspondingly less. The improvement will be less for low-band monitors than for high-band monitors, because of the lower RF frequency.

Besides frequency measurements, the FCC also requires a routine check of the transmitter deviation. The Motorola Monitor can be used for this purpose, the deviation-measuring system being as follows:

The deviation meter of the monitor is located at the output of the audio section of the standard receiver; hence the output voltage will vary with the gain of the audio stages. Internal calibration is provided, however, in order to insure that the recorded deviation is correct. The output of an internal audio oscillator is set to a predetermined level (as measured by the meter), and the gain of the audio section is then adjusted by applying this known audio voltage to the audio amplifier and setting the volume control for a specified output voltage. In this manner the gain of the entire audio section is maintained at the correct level, and the deviation shown on the meter will be correct. The procedure (fig. 2) is as follows:

First adjust the oscillator output for the correct voltage. This is done by connecting the deviation meter to the output of the oscillator, and adjusting the oscillator output to a specified level. This level will vary with each instrument, but a tag will be found on the unit which provides the correct reading. The next step is indicated in figure 2B. The audio oscillator is applied to the receiver audio section, and the meter is placed at the output. The volume is then adjusted for a 15-kc deviation reading on the meter. With the input and output voltages known, the correct audio gain of the receiver is established. Thus the meter will indicate accurately the deviation of the incoming RF signal, for the audio output of the discriminator is determined by the deviation of the signal into the discriminator and this discriminator output is applied to the audio section of the receiver.



Either the Motorola Monitor or the Frequency Meter may be Used to Determine the Frequency of a Transmitter.

The RF is now applied to the monitor. This procedure is much the same as for frequency measurements, but the controls have now been adjusted to show the amount of deviation. The manner of adjusting the transmitter control will differ according to the type of test modulation, whether sinewave or voice. The instruction manual for the instrument should be consulted. It should be kept in mind that the monitor meter movement responds to average readings of the applied signal, although the meter dial is marked in peak deviation. When the modulation signal is sinusoidal, the peak and average readings have a normal relationship and the meter reading is accurate. In the case of nonsinusoidal modulations, however, the actual peak deviation may not coincide with that shown on the meter.

Pursuing this subject further, only when the audio voltage is a sinewave will the relationship between the average value and the peak value result in a correct meter indication. The average and peak values of other waveforms may have different relationships and the peak indication shown on the meter will not necessarily be the true peak deviation. This must be taken into consideration when using the Motorola Monitor for measuring deviation (and adjusting the transmitter modulation).[1]

Depending upon the equipment available and the type of modulation, there are several different procedures for measuring deviation. We shall discuss them briefly.

Assuming that we are to use the Motorola monitor to measure deviation (of a Motorola G-type transmitter) resulting from voice modulation, we introduce a sustained “Ah-h-h-h-h” of good volume at

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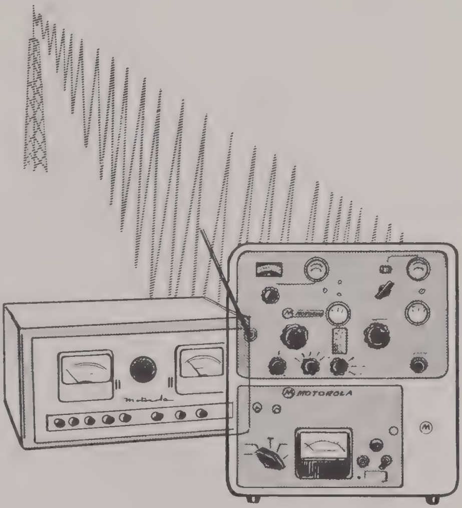
1. See reference M-6, "Let's Measure Modulation."

the transmitter microphone. The reading on the monitor meter should be about 12 kc. When we talk into the microphone, the average deviation will read about 7 kc on the meter, with the peaks at about 10 kc. The true deviations are actually higher than these indications, but the meter does not follow the instantaneous modulation of the voice signal.

Deviation may also be measured by means of a 1000-cps audio oscillator, an AC voltmeter and the monitor. With an audio input of at least 1 volt to the transmitter, the monitor should read 13 kc. This reading is lower than the true deviation of 15 kc, due to the variance of the average-peak relationship of the modulating waveform when the audio circuits of the transmitter are in full clip.

Another, and very reliable, means of determining the deviation requires the use of a scope, which must first be calibrated so that the amount of vertical deflection in relation to the deviation is known. For this purpose, the scope is connected to the output of the discriminator in the monitor, and a 1000-cps audio sinewave signal is applied to the transmitter input. This signal must be kept below the clip level during the calibration procedure. The audio is adjusted for a 10-kc reading on the monitor meter and the scope vertical gain is adjusted for a convenient deflection such as 10 full squares on the screen. Each square now represents 1 kc of deviation and we have a very sensitive indicator. Any means may now be used to modulate the transmitter and the scope will show the true deviation.

The above discussion is based on a system deviation of 15 kc. Where the deviation is limited to 5 kc, we use this as the maximum value, with 3.5 kc now corresponding to the 13 kc mentioned above. For 5-kc deviation systems, the scope again is an accurate and convenient means of measuring deviation.



The Motorola Monitor and Frequency Meter will Also Measure the Deviations of an FM Transmission.

Heterodyne Frequency Meters

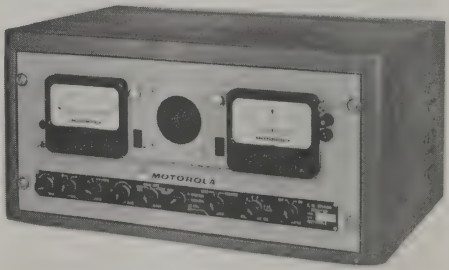
There are several types of frequency measuring meters, most of which make use of a highly stable and carefully calibrated oscillator. This oscillator is heterodyned or beat with the carrier to be measured. When a zero beat occurs, the calibrated oscillator is at the same frequency as the unknown carrier; the frequency may then be either read directly on the dials of the calibrated oscillator or determined from previously prepared charts. The basic system is shown in the block diagram of figure 3A.

The carrier which is to be measured is applied to a mixer along with the output of the calibrated oscillator, and the oscillator is adjusted to the approximate frequency of the carrier. As the frequency of the oscillator swings through the frequency of the carrier, their difference frequency will be heard in the headphones; the operator will first hear a high-frequency sound which gradually decreases in frequency until the zero beat is detected. As the oscillator frequency is further varied we again hear a difference frequency in the phones, only this time it starts at a very low frequency and the frequency increases until it is beyond the range of the equipment or the hearing range of the operator.

At zero beat, the oscillator frequency is the same as that of the carrier, so the carrier frequency is established by determining the frequency of the oscillator. On some instruments the frequency is read directly from the instrument dials; on others, it is necessary to determine the frequency from charts supplied with the instrument.

Without some means of calibrating the variable oscillator of the heterodyne type of frequency measuring instrument, the guaranteed accuracy would be poor and the instrument would not be acceptable for measuring the frequency of two-way communications transmitters. (The FCC requires that the accuracy of the instrument be twice as good as the required stability of the transmitter.)

In order to provide this higher degree of accuracy, a calibrating, crystal-controlled oscillator is included in the equipment of figure 3A. The frequency of the variable oscillator may now be calibrated against the crystal oscillator at the fundamental crystal frequency, at any harmonic of the crystal frequency, or at any combination of harmonics of the oscillators where their frequencies coincide. For example, let us assume that the crystal is 5 mc. The variable



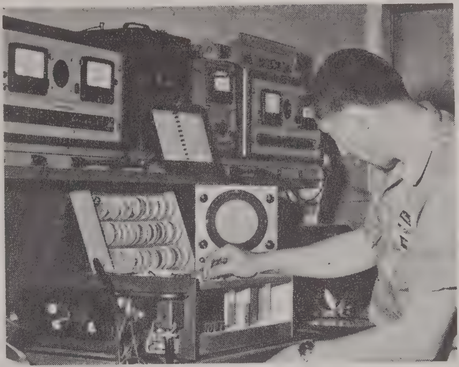
In Addition to Monitoring a Desired Channel, the Motorola Monitor Measures Transmitter Frequency and Deviation.

oscillator has a check point at each megacycle. At 1 mc its fifth harmonic is 5 mc and a zero beat is detected when the oscillator is adjusted to exactly 1 mc. At 2 mc the oscillators have a common harmonic frequency at 10 mc to provide the zero beat. At 3 mc the common harmonic is 15 mc, and so on. Harmonic beats are thus heard throughout the range of the variable oscillator.

Now let us suppose that we require a frequency check of a transmitter operating at a frequency of 39.97 mc. The variable oscillator is first calibrated against the crystal oscillator at 40 mc, the closest check point. The two internal oscillators are applied to the mixer, with the variable oscillator dial set at exactly 40 mc. A small calibrating control is now adjusted for zero beat. The oscillator is now at 40 mc and, because 39.97 mc is very close to this check point, the measurement at 39.97 mc will be very accurate. (The further the frequency being measured is removed from a check point, the greater will be the chance for error.)

Where the frequency range of the instrument is lower than the frequency of the carrier being measured, the harmonics of the variable oscillator will provide the necessary beat signal.

In figure 3B, a variation of the basic system of figure 3A, two separate oscillators (one crystal controlled and one variable) are combined to produce the heterodyning signal. By using harmonics of the crystal controlled oscillator, and combining the output of both oscillators, the instrument supplies an accurate signal at the desired frequency.



Besides Measuring Transmitter Frequency and Deviation, the Motorola Frequency Meter may be used as a Generator for "Netting" Receivers.

One of the inherent advantages of this instrument is the frequency stability of the crystal oscillator, which determines to a considerable degree the stability of the output. The harmonic amplifier provides signals at 1-mc intervals throughout the operating range of the instrument. The low-frequency oscillator is variable from 1 mc to 2 mc. By combining these two signals, then, we have an output which is continuously variable. (This variable oscillator is readily calibrated at 1 and 2 mc by beating it with the crystal oscillator.)

The harmonic amplifier is tuned so that the output at the desired harmonic is maximum. In addition, the dial (used for tuning for this maximum output) is calibrated according to the frequency generated in the mixer, thus providing an indication of the "megacycle" portion of the signal. The "kilocycle" portion of the output is determined from the calibrated dial of the variable oscillator, also calibrated according to the frequency produced at the mixer.

The heterodyne type of frequency measuring instrument (figures 3A and 3B) may also be used as a signal generator. The desired frequency is selected on the instrument and the output is taken from the "input" terminals.[2]

Deviation Meters

Deviation meters are basically highly calibrated FM receivers; the output from the detector must be a function of the amount of deviation and this output must be indicated on a meter. If the meter reading should change with variations of input signal strength, or with the gain of the receiver, the indicated deviation will not be accurate.

The method used for converting the carrier frequency to the operating frequency of the discriminator is unimportant when measuring deviation, as the amount of deviation is not altered by frequency conversion. If we are to establish an accurate indication of the deviation, however, two things are essential.

First, the output of the discriminator must be a function of the amount of deviation but not of the strength of the signal. If the output of the discriminator should change with signal strength, we do not have a reliable indication. By providing full limiting in the receiver for all incoming signals, the discriminator will respond only to frequency changes.

Second, the gain of the amplifier stages between the discriminator output and the indicator must remain constant. Usually one or two stages of amplification are required, and if the gain of these stages changes, the meter reading is not reliable.

The metering circuit for indicating the amount of deviation may respond to the peak deviation or it may respond to the average deviation. It is important for the serviceman to know the characteristics of his instrument if he is to use it intelligently.

Interpolating Vernier Dials

Many heterodyne type frequency meters are equipped with vernier dials, which provide accurate readings to five figures. A typical arrangement is shown in figure 3C.

The system is as follows. The first two digits (hundreds) are found on the hundreds dial. Here

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2. See Test Methods, section 2, pages 36-38 and section 3, pages 11-14.

The Motorola Transistorized AC Voltmeter Will Measure Small AC Voltages Accurately and is Very Useful in Trouble Shooting Low Level Audio Circuits.

the reading is 3900, because the reference line is between 39 and 40.

The next two digits (units) are found on the inside circular dial. The marker for this dial is the zero reference line on the outer scale, which is between 27 and 28, so the next two digits are 27. The first four digits are 3927, and it remains only to read one more digit (tenths).

This final digit is read on the tenths vernier (the outer circular scale marked from 1 to 10). Whichever line of the vernier that coincides with (or is closest to) a line on the inner dial becomes the fifth digit. In figure 3C, the 33 on the inner scale is next to 7 on the vernier scale, so the final number is 7, and the complete number is 3927.7.

The ultimate accuracy of a vernier reading is always subject to a certain amount of "backlash." No matter how well the mechanism is constructed, there is always some backlash present and the readings can be expected to vary, according to whether the dial was rotated from a higher setting or from a lower setting. While the instruction book for any instrument should be followed in detail, it is customary to approach a setting from the low-frequency side and for the dial to have at least one full turn.

Once the dial reading has been determined, it must be converted to the corresponding frequency. A conversion chart is furnished with the instrument, but it is often arranged in 1-kc steps and does not include the in-between frequencies. It thus becomes necessary to interpolate the readings in order to obtain the exact frequency.

Suppose, for example, that the conversion chart indicates a frequency of 2420 kc for a dial reading of 3934.9, and 2419 kc for a dial reading of 3926.8. The dial reading of 3927.7 in figure 3 thus represents a frequency somewhere between 2419 and 2420 kc. The difference between the two dial readings shown on the chart (3934.9 and 3926.8) is 8.1. The actual dial reading (on the meter) is 3927.7, or 0.9 higher than the chart reading, which represents 2419 kc. The value 0.9 is only 1/9 the total difference (8.1); hence, the frequency difference is 1/9 of 1 kc, or 111 cycles. Adding this to 2419 kc, the frequency is found to be 2419.111 kc.

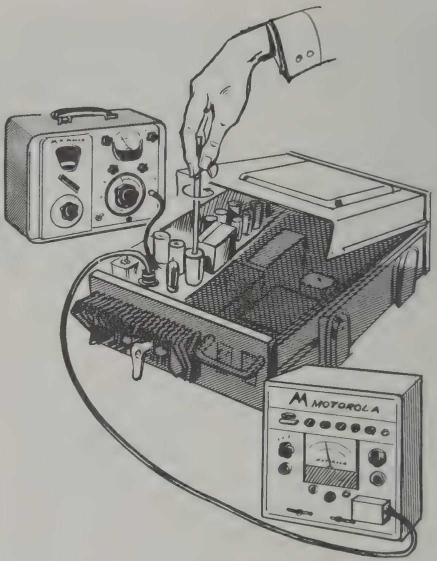
Some dials may differ slightly from the one shown in figure 3C, but the system of interpolating the reading remains the same.

AC Voltmeters

The AC VTVM is another important instrument in the servicing of two-way equipment. The ordinary VTVM is usually not satisfactory because its range is not low enough to provide accurate readings for small AC voltages. Besides having a high impedance, the AC meter must be capable of indicating small voltages in order to be useful to servicemen.

Microphone and other audio devices often have outputs of less than one volt, and it is essential to have an accurate means of measuring such voltages.[3]

We see from the above that the low scale of the meter should require no more than 1 volt for full-scale deflection. The manual for a particular 450-mc base station, for example, may state that the input level is 0.10 volt. Unless the scale used is at least as low as 1 volt, the meter deflection will not be sufficient to measure this value accurately. (The newer Motorola test set, Model TU546, provides for low-level AC voltage measurement facilities.)



A Signal Generator and the Test Set are Recommended for Aligning Motorola Receivers.

A sensitive oscilloscope can be used instead of the AC voltmeter, and the scope can be accurately calibrated. Its limited portability is generally objectionable, however. While not essential, it is always convenient for the AC voltmeter to be portable, as the serviceman must often use this instrument where no AC power is available.

Wattmeters

One of the most practical instruments for the service and maintenance of two-way equipment is the wattmeter. This instrument is valuable not only for aligning and trouble shooting the transmitter; it can be used also for trouble shooting the antenna system.

Wattmeters are of two general types. One type is terminated in a specific load which matches the impedance of the antenna system, the meter being used to measure the amount of power delivered to that load. The other type uses the antenna system as the load and merely measures the power being transferred from the transmitter to the antenna. This type of wattmeter can be used to measure both forward and backward power. That is, the meter will indicate the amount of power returning from the antenna to the transmitter as well as the power being delivered from the transmitter to the antenna.

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[3] See Test Methods, section 2, pages 11-18.

Wattmeters indicate the power directly when they terminate in a dummy load. It is important, however, (1) that the terminal impedance be matched to that of the antenna system--namely 50 ohms, (2) that the range of the meter include the transmitter frequency, and (3) that the power rating of the meter be adequate for the equipment being measured.

The Motorola test set may be used in conjunction with the Motorola dummy antenna in order to measure RF power. The dummy antenna includes a rectifier and meter calibrating resistor, which are used for measuring the current. Conversion tables are then consulted to determine the corresponding RF power.

By knowing the amount of power being delivered to the load, it is possible to adjust the transmitter for maximum output. Since the antenna has the same impedance as the dummy load, the tuning procedure does not change and the final settings will be the same when the antenna is substituted for the wattmeter and load. If the antenna is not perfectly matched to the transmitter, however, the settings may have to be changed when the antenna is substituted for the dummy load.

The wattmeter, when placed directly in line with the antenna, depends upon the antenna itself for the load, and it often proves to be a valuable instrument not only for checking the efficiency of the antenna system, but for measuring the RF power output of the transmitter as well.

This type of wattmeter is capable of measuring the amount of RF power reflected from the antenna to the transmitter as well as the amount of power delivered from the transmitter to the antenna. The difference between forward and backward power furnishes an indication as to whether the power reaching the antenna is actually being radiated into space as a radio wave, or returned from the antenna to the transmitter. This illustrates the importance of maintaining correct impedances. Unless the proper impedances are maintained, the power cannot be radiated by the antenna and must return to the source. If the impedance mismatch is as much as 2 to 1, the power loss is 11 per cent.

When measuring antenna power, the possibility of transmission line losses must also be taken into consideration. Suppose, for example, that the meter is placed between the transmitter and the transmission line. Any forward power indicated on the meter will represent the actual power being transferred to the antenna. The reflected power reading, however, may not show the true picture, for the reflected power reading is affected by the power loss in the transmission line, both going to the antenna and returning in the line to the transmitter.

This New Motorola Signal Generator Covers All the Frequency Bands Used for Two-Way Communications.

Let us further suppose that the transmission line in the above example offers a total loss of 6 db at the operating frequency and that the power available at the transmitter is 100 watts. With a 6-db loss in power (a power ratio of 4 to 1), the power reaching the antenna will be only 25 watts. Now let us suppose that the antenna is not properly matched and that only half of the power reaching the antenna (12.5 watts) is radiated, the other half (12.5 watts) returning from the antenna to the transmitter. This means that the reflected power at the antenna is 12.5 watts, but only one-fourth of this power reaches the transmitter, for again there is a 6-db loss and the reflected power at the meter is more than 3 watts. The meter at the transmitter thus indicates that the forward power is 100 watts and that the reflected power is 3 watts. Disregarding any loss in the transmission line, it would seem that the antenna system was satisfactory. On the contrary, however, the true story can be found only at the antenna end of the transmission line. A wattmeter at this position will show that the forward power is only 25 watts and that the reflected power is actually 12.5 watts--a very undesirable condition.

The cause of the above condition is twofold. For one thing, the antenna is not proper, as indicated by the high percentage of reflected power. For another thing, the 6-db loss of power in the transmission line indicates that the line is at least improper--if not actually defective--and that a different type of line, one that does not have so much loss, should be used.

Signal Generators

The RF signal generator which has an accurately calibrated output can be one of the most practical among the various measuring and trouble-shooting instruments used by the serviceman working on two-way equipment. This instrument is not essential as far as FCC requirements are concerned, but it is very convenient for checking the operation of a receiver.

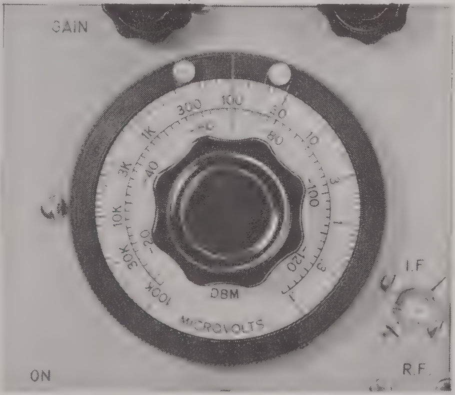
The Motorola test set is accurately calibrated for IF alignment when a 455-kc crystal is used. Hence, the frequency calibration of the RF signal generator is not as important as its indication of the output signal level. Sensitivity is one of the primary considerations of the communications receiver; without a signal generator to determine the 20-db quieting level, it is hard to tell when the receiver is working at its full rating.

By using a generator (such as the Motorola TU576, or equivalent) together with an output indicator for the receiver (the Motorola test set provides this function), the sensitivity of the receiver can be measured in a very short time. This arrangement is very helpful both in alignment and in trouble shooting.

When aligning the receiver, the generator conveniently provides an RF signal having a predetermined level. The Motorola test set then indicates the output for the various circuits and the latter are adjusted to any level required. After all circuits have been adjusted, the RF level of the generator will indicate the exact sensitivity of the receiver.

When trouble shooting the receiver, the generator provides a substitute signal, and the frequency and level of this signal may be varied as required. Stage gain measurements can thus be made by the serviceman in order to determine the operation of each section of the receiver. (If the serviceman knows the amount of input voltage which is required in order to produce a specified output voltage for a particular stage, the exact location of a defective section can be easily determined.)

When using the signal generator with a receiver, it is important to provide the proper impedance match. Otherwise, the voltage indicated by the generator will not be accurate; measurements will be meaningless. This readily accounts for differences in readings when several generators are used. Unless the generator is properly terminated and unless the correct cabling and termination is provided, valid measurements cannot be obtained.



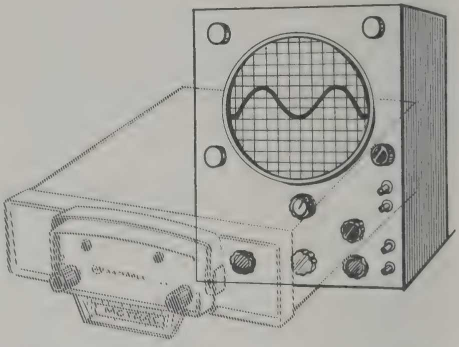
Here We See the Level Adjusting Dial of the Signal Generator. The Setting Accurately Indicates the Generator Output Voltage.

The accuracy of the output voltage furnished by the signal generator can be completely nullified if there is an appreciable amount of leakage RF. It will be obvious that a generator which radiates more signal into the receiver than that provided at its output terminals would be nearly useless at low signal levels.

The range of the instrument should include all frequency bands for the equipment being serviced --ideally from 5 mc to 1000 mc for equipment used in two-way communications. While few present-day receivers operate in the 900 mc band, it is probable that more receivers will use these high-frequency channels in the future. This frequency setting need not have a high degree of accuracy, it is true, but it is essential for the generator to have good frequency stability. The low-frequency range also finds no direct use as a channel frequency, but the 5-1000 mc generator provides the necessary output often required when aligning the high-frequency IF sections of receivers.[4]

Oscilloscopes

While the "scope" cannot be regarded as an essential piece of test equipment (since service work can be performed without one), its versatility makes it an invaluable instrument in all kinds of service work.



A Scope is Very Useful in Adjusting the IDC Circuit and Trouble Shooting the Audio Section of the Transmitter.

The scope is capable of indicating and measuring almost any electronic factor that is usually measured by a meter (frequency, waveform, phase, amplitude, etc.). It is particularly convenient when used in conjunction with a deviation meter. While any of the deviation meters discussed in this lesson can be used to indicate average or maximum deviation, it is not possible to record both values on the same instrument, nor is it possible to determine the exact modulation pattern being measured. The scope, however, indicates the actual waveform of the signal, and when it is calibrated according to its vertical deflection, the exact peak deviation is indicated. Furthermore, oscilloscope patterns for the voice range are entirely independent of frequency. When used in connection with the operation of the transmitter IDC circuit, the scope will indicate the exact point of clipping and the operating waveforms.

While the average serviceman is acquainted with the general op-

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4. See Test Methods, section 2, pages 61-68.

eration of this instrument, it may be well to review the basic circuit. Figure 4 shows the functions of the various sections of a typical model.

The scope is designed about the cathode ray tube (CRT). Deflection plates in the CRT allow the electron beam to be bent vertically and horizontally, and a waveform is thus produced according to the nature of the deflecting voltages applied to these plates.

The horizontal deflection is normally a sawtooth wave wherein the beam is gradually pulled from the left-hand side of the tube to the right. When the beam reaches its extreme right excursion the waveform changes, returning it very quickly to the left-hand side. The cycle is then repeated continuously. The horizontal deflection plates in figure 4 are connected to the output of the horizontal deflection amplifier. The amplifier input comes from the sweep (sawtooth) generator and its frequency is variable. This sweep waveform is triggered by the vertical section when the sync selector switch is at INT. A small portion of the vertical deflection voltage is then applied to the horizontal generator in order to synchronize the horizontal sweep frequency with the frequency of the vertical voltage.

The desired waveform is applied to the vertical amplifier and the output impressed upon the vertical deflection plates. Gain controls are provided for both vertical and horizontal deflection voltages, and the pattern may be shifted either to the right and left or up and down, by the two positioning controls, R3 and R4.

The exact manner in which the waveform is produced on the CRT screen is thoroughly explained in other publications and need not be repeated here. We are interested, rather, in the practical use which can be made of the waveform thus produced.

By knowing the nature of the waveform applied to a circuit, and then comparing it with its successive representations as it passes through the various stages, the operation of these stages can be evaluated, particularly with respect to gain and distortion.

In the audio section of the transmitter, the waveform of the audio modulating voltage is of particular interest, for the entire purpose of this section is to control the amplitude and waveform of the voltage applied to the modulator. By observing the waveform at successive stages within this section, operation of each portion of the circuit can be evaluated and any inoperation or malfunction immediately pinpointed. Moreover, the vertical deflection can be plotted against vertical input voltage, which enables the serviceman to ascertain the various levels of audio voltage from point to point within the circuit.

Typical audio waveforms within the transmitter are shown in figure 5. The left-hand column shows waves produced as a result of clipping, at various voltage levels. The right-hand column shows the resulting waveforms, respectively, at the output of the integrator. The upper waveforms show no change from the original sinewave, which means that the amplitude is not sufficient to cause clipping, and the sinewave is not altered by the integrator. The lower waveforms show what happens when the input voltage is very high. The severe clipping of the wave produces a square wave output and the integrator changes the square wave into a triangular wave. The waveforms in between these two extremes represent various degrees of clipping.

Distortions within the audio section of the receiver are readily located by means of the scope, and they can be quickly pinpointed with this instrument to a definite section. This is done by putting the input audio signal on the scope and then following it through the circuit. Any deviation in the original waveform indicates some kind of distortion.

Since the exact signal level can be determined by means of the scope calibration, the instrument thus becomes a sensitive AC voltmeter. By comparing the input amplitude of a stage with the output, the stage gain can be determined. Coupling circuits may show a high degree of attenuation from the plate of one stage to the grid of the next stage, automatically indicating a defective circuit. Open coupling capacitors are readily located by this method although they cannot be discovered by means of voltage or resistance tests. When checking coupling circuits, the serviceman must remember that some attenuation will always be encountered, and that it will be greater at the lower frequencies than at the higher frequencies, resulting in a proportionally greater loss. This is particularly true where the coupling capacitance is relatively small.

The scope finds good use in connection with the Motorola Monitor in measuring deviation. Test calibration circuits in the instrument allow a quick calibration of the vertical deflection at 15 kc, and the gain of the scope can be adjusted for a convenient deflection at 15 kc. The gain of the scope can then be adjusted for a convenient deflection with this known voltage applied. Then, when a signal is applied to the instrument, the amount of deviation can be immediately determined by means of the deflection produced. Observation of the waveform shows both peak and average deviation.[5]

The Test Bench

Figure 6 shows a practical test bench which includes the test equipment necessary for properly servicing two-way radios. On the upper shelf from left to right we have the Motorola frequency and deviation meter, the Motorola transistorized AC voltmeter, the Motorola test set, a dummy antenna, an RF wattmeter, and the Motorola Signal Generator.

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[5] See Test Methods, section 2, pages 40-53.

Other test equipment includes a power supply for bench operation of mobile radios, a filter for operating transistorized receivers, a meter panel which allows for simultaneous monitoring of the various receiver circuits, and battery testers.

On the work shelf we see a typical two-way radio, this particular model being a "Motrac" unit, which includes a completely transistorized receiver and power supply. Additional tools, cables, service manual, etc., may be kept in the storage areas below.

STUDENT NOTES

STUDENT NOTES

STEP 1
CALIBRATE 5MC CRYSTAL OSCILLATOR WITH WWV

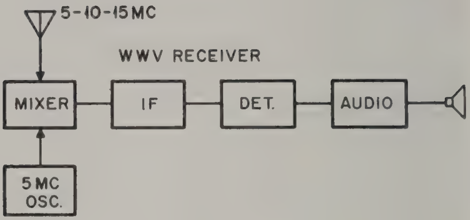


FIGURE 1A

STEP 2
USE 5MC OSCILLATOR TO CALIBRATE THE CONTROL RECEIVER TO 150MC

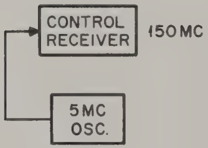


FIGURE 1B

STEP 3
DETERMINE THE CORRECT CRYSTAL FREQUENCY

FIGURE 1C

152.5 (CHANNEL FREQ.)
−150. CONTROL RECEIVER
2.5 MC

STEP 4
WITH CORRECT CRYSTAL IN OSCILLATOR, APPLY OSC. AND RF SIGNAL BEING MEASURED TO MIXER. MIXER OUTPUT IS APPLIED TO CONTROL RECEIVER AND DISCRIMINATOR OUTPUT INDICATES FREQUENCY OF RF SIGNAL

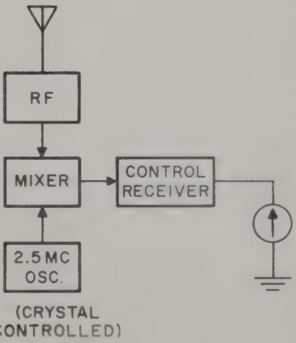


FIGURE 1D

FREQUENCY MEASUREMENTS
USING THE MOTOROLA MONITOR

FIGURE 1

STEP 1
ADJUST AUDIO OUTPUT
TO SPECIFIED READING
ON DEVIATION METER

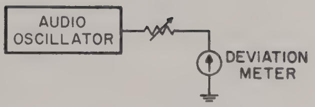


FIGURE 2A

STEP 2
ADJUST AUDIO GAIN
FOR 15KC DEVIATION

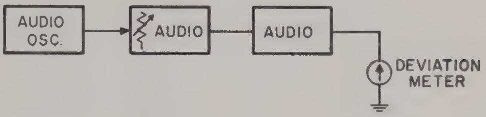


FIGURE 2B

STEP 3
READ DEVIATION
ON METER

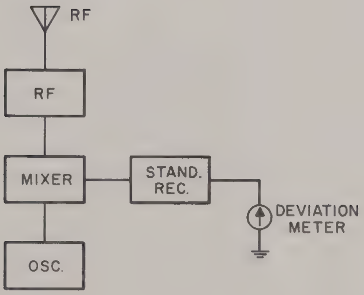


FIGURE 2C

USING THE MOTOROLA MONITOR
TO MEASURE DEVIATION
FIGURE 2

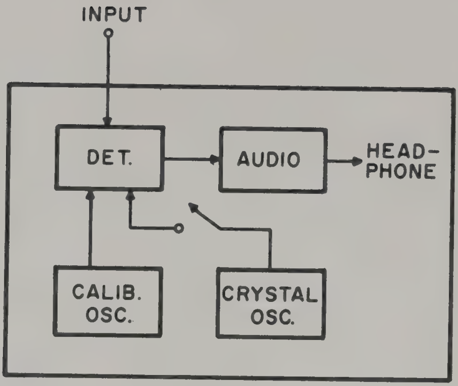


FIGURE 3A

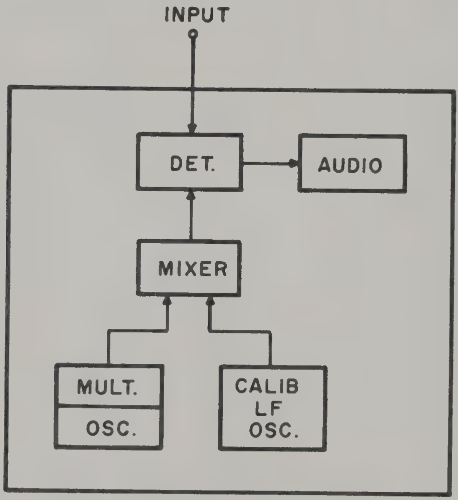
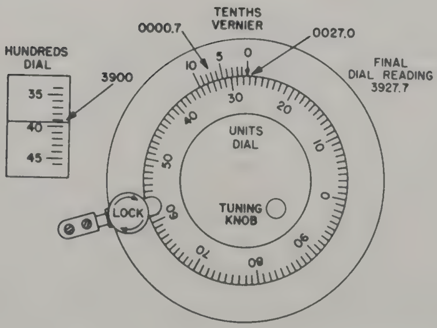


FIGURE 3B

HETRODYNE METERS



DIAL OF A TYPICAL HETERODYNE FREQUENCY METER

FIGURE 3C

STUDENT NOTES

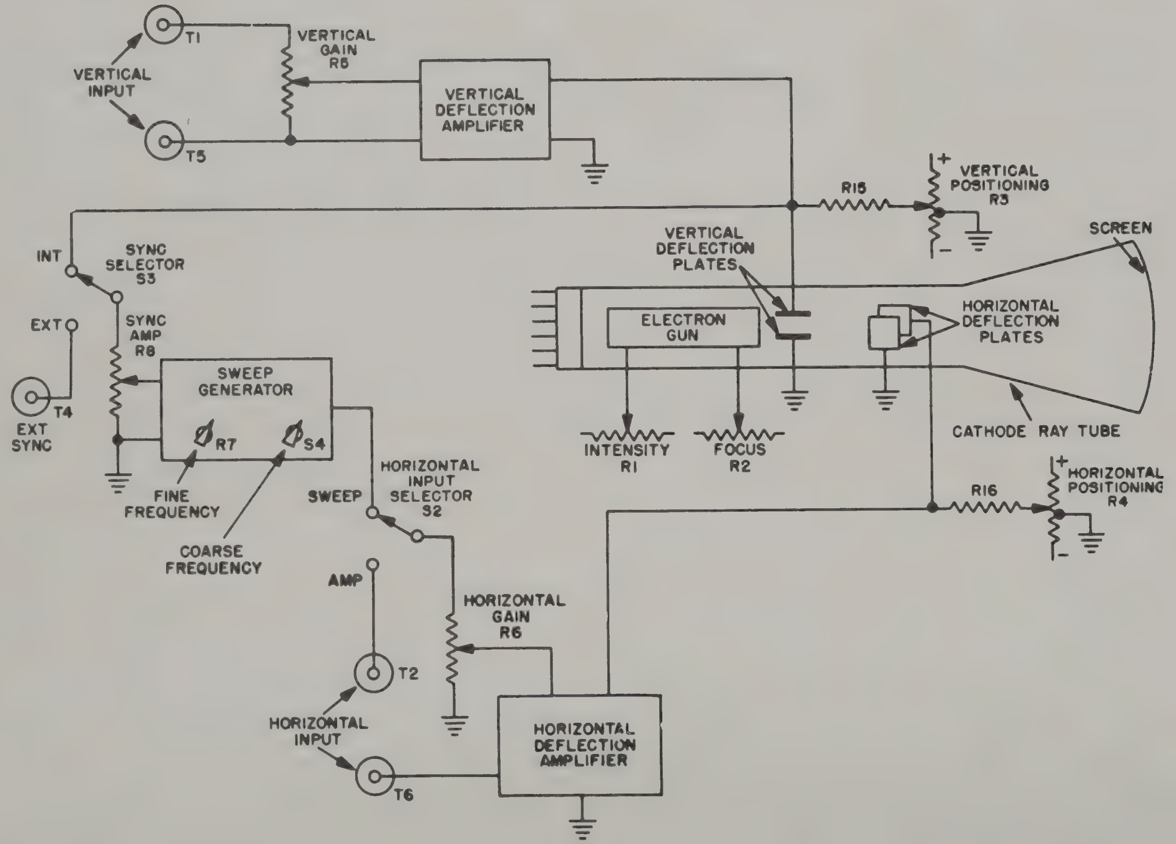
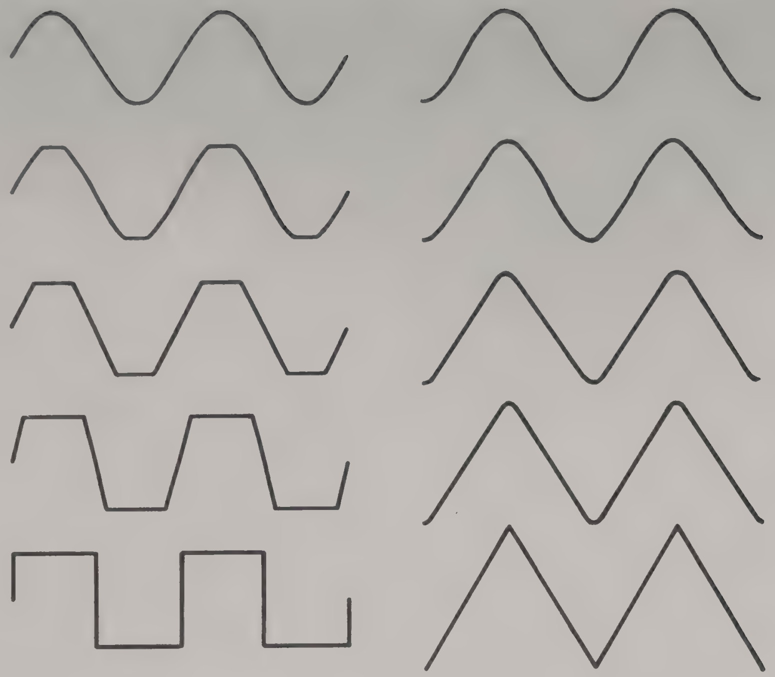

VERTICAL INPUT
T1
T5
VERTICAL GAIN R5
VERTICAL DEFLECTION AMPLIFIER
R15
+
VERTICAL POSITIONING R3
-
INT
SYNC SELECTOR S3
EXT
SYNC AMP R8
T4
EXT SYNC
SWEEP GENERATOR
R7
S4
FINE FREQUENCY
COARSE FREQUENCY
VERTICAL DEFLECTION PLATES
ELECTRON GUN
INTENSITY R1
FOCUS R2
SCREEN
HORIZONTAL DEFLECTION PLATES
CATHODE RAY TUBE
R16
+
HORIZONTAL POSITIONING R4
-
SWEEP
HORIZONTAL INPUT SELECTOR S2
AMP
HORIZONTAL GAIN R6
T2
HORIZONTAL INPUT
T6
HORIZONTAL DEFLECTION AMPLIFIER

FIGURE 4



SINE WAVES WITH VARIOUS DEGREES OF
CLIPPING, BEFORE AND AFTER INTEGRATING

FIGURE 5

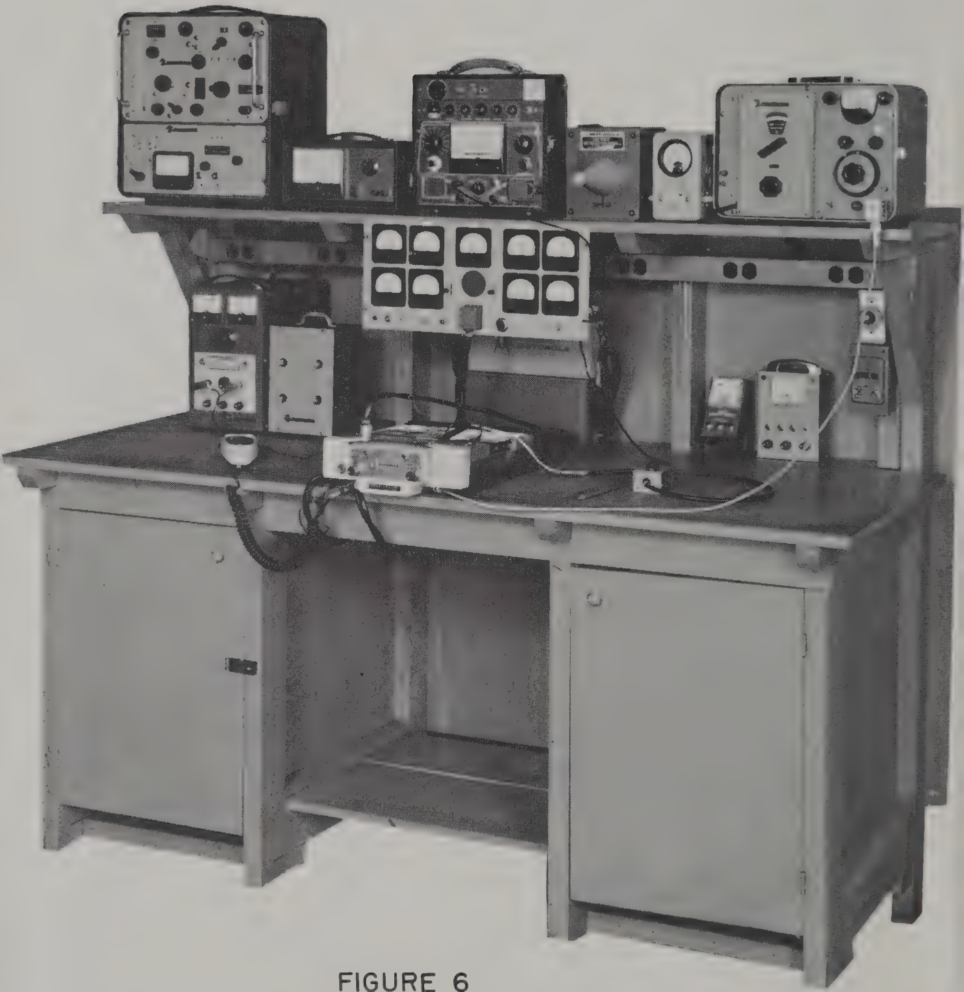


FIGURE 6

national
MOTOROLA
RADIO COMMUNICATIONS
service

A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON MA-8
MAINTENANCE

Installations and Preventive Maintenance

MOTOROLA TRAINING INSTITUTE

A TWO-WAY RADIO COMMUNICATIONS TRAINING PROGRAM

LESSON MA-8
MAINTENANCE

Installations and Preventive Maintenance

—one of a series of lessons on two-way FM communications—

MOTOROLA **TRAINING INSTITUTE**
4501 W. AUGUSTA BLVD., CHICAGO 51, ILLINOIS

APPROVED BY THE STATE OF ILLINOIS
DEPT. OF REGISTRATION AND EDUCATION

PREFACE

This is one lesson of a complete Motorola Home-Study Course which presents to the Service Technician both the principles of operation and the maintenance of two-way FM radio systems. The program covers mobile, portable and base station equipment, including the latest transistorized units.

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TWO WAY INSTALLATIONS AND PREVENTIVE MAINTENANCE

LESSON MA-8

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NOTICE

Diagrams and figures referenced in text are "fold-outs" in back of each lesson, for use while studying. The Examinations are also there.

You'll find two-way mobile radios installed in all types of vehicles--from the smallest foreign car to the largest earth-moving or machinery handling type of equipment.

TWO-WAY INSTALLATIONS AND PREVENTIVE MAINTENANCE

Lesson MA-8

Introduction

In this lesson we shall discuss the installation of two-way communications equipment. If the equipment is to continue to perform with maximum efficiency and reliability, it is essential for it to be properly installed and procedures must be followed to insure satisfactory operation of the equipment. A good installation also reduces the amount of future maintenance required on the system. In addition to installation techniques, we shall talk about the routine maintenance which must be practiced in order to assure continued good performance. Let us start our lesson by discussing the installation of a mobile two-way station.

Mobile Installations

After the equipment has been unpacked, inventoried, and inspected for possible damage, the complete installation must be planned. This will be governed by the car or vehicle in which it is to be installed. For our example we shall assume that a rear mount installation is to be made in a commercial car or cab. (It will have been previously determined whether the installation is to be a front mount or a rear mount.) The instruction manual must be studied carefully. Diagrams such as figure 1 and 2 are supplied to show the recommended location of the various units and their proper interconnections.

After the installation has been planned, the serviceman should proceed according to the suggestions in the manual. The housing for the receiver, transmitter and power supply is first installed. The drawer unit is removed and the housing located so that the drawer unit is accessible and can be readily removed for service. A minimum of 3 or 4 inches is required in front of the split-type housing--see figure 1. The housing must be well grounded to the car frame.

All paint and dirt must be scraped off and the surfaces burnished (with steel wool) to insure good contact. When mounting holes are being drilled, care must be taken to prevent the drill or mounting screws from coming too close to the gas tank or gas line.

The components inside the car may be mounted next. These include the control head, the microphone and its hang-up bracket, and the speaker. The control head along with the bracket for the microphone are mounted on the dash, so that it is conveniently accessible to the operator. The microphone may require connections within the control head or a plug connector may be provided, depending upon the equipment. Details are incorporated in the manual. The speaker is mounted in the most convenient place which will provide maximum audibility to the operator, and interconnections are made between the speaker and control head.

The fuse block and A power relay are next mounted, either on the engine side of the firewall or on the fender panel. The fuse block is located close to the battery, and the relay should be near the fuse block. The relay should be mounted with its contacts pointing down to avoid moisture accumulation inside the relay can. The cabling may now be installed.

Figure 1 shows the approximate path of the cables between the front units and the housing. The exact routing will depend upon the type of vehicle. (In some of the new cars, certain cable routings could conceivably require a longer cable than that supplied. For this reason, it is well to consider the cabling before mounting the individual parts--it may be necessary to relocate a few of the units. In most installations the cable is longer than necessary and the "extra" is coiled up, taped, and positioned out of the way.)

Always "Take Inventory" and Plan Each Installation.

We shall consider the antenna installation next. It may be located either in the center of the roof or on a fender. (See figure 1.) High-band or 450-mc equipment requires a roof mount for optimum operation. The length of a low-band whip antenna often makes it impractical to mount it on the roof top; unless maximum sensitivity is required, it may be mounted on the fender.

Where some peculiarity of a particular installation makes it impossible to follow the instructions in the manual, the solution must be logical. It must not interfere with the operation of the unit. When mounting the various units, all mounting screws must be firmly tightened. The correct size holes are specified to insure a good contact. If the vehicle is to be subjected to excessive vibration, suitable mounting nuts, bolts and washers may be substituted for those recommended in the manual. There is more to the complete installation than the mere mounting and cabling of the equipment. In addition to the noise filtering which may be required, the frequency, deviation and power must be checked in order to insure satisfactory system operation. The receiver, too, should be checked for sensitivity, squelch operation, and noise balance. The list which appears later in this lesson will serve as a guide for checking out the entire equipment. All readings which are taken should be recorded and retained for future reference.

Base Station Installation

Installation problems with base stations are different from those encountered with mobiles. The primary power available at the site must have sufficient voltage regulation. If not, some means must be provided for controlling the voltage at the equipment. Where the base station is remotely controlled, moreover, the control line must have certain critical characteristics. DC is normally used for operating the relays which switch the equipment between standby and transmit. Besides providing a good DC path, the control line must also carry the modulation, so its frequency characteristics must be satisfactory for voice transmission. The db loss of long lines is thus an important consideration.[1]

The site chosen for the base station equipment should be easily accessible to the serviceman and it must meet all code requirements (fire department, building department, electrical department, etc.)

The antenna must be carefully located so as to avoid interfering with other services. It must not cause intermodulation and desensitization in other local receivers due to its proximity with other antennas. At the same time, the site must provide complete coverage of the service area. The base station antenna must be mounted so that it will withstand the elements, and proper lightning protection is a must. Where a directional antenna is used, it must be properly oriented. The transmission line must be properly installed and secured and, where air or gas lines are used, the proper pressure must be established.[2] The line must be well grounded where it enters the building, and a drip loop should be used. This prevents water from entering the building or equipment via the line. In some base station installations, cavities are included to prevent interference; these must be properly tuned. Tower lights must be capable of being turned off and on at the proper time, and this must be verified.

Proper clearance for the front and back doors must be provided when installing the cabinet. Upright type cabinets must be securely bolted down and grounded. Emergency power, if provided, should be checked to make sure that it operates properly.

---

1. See "Hum Reduction in Remote Control Lines," reference M-8A.
2. See reference T-12A.

The Microphone of the Mobile Two-Way Radio Must be Within Easy Reach of the Operator.

The base station must be checked and a log established, according to FCC regulations. A record should be kept of all readings such as power output, receiver sensitivity, etc.

Noise Suppression in Mobile Equipment

Noise encountered in the mobile two-way radio equipment may be caused by the ignition and electrical system of the vehicle in which the equipment is installed, or it may be reaching the receiver through the antenna system along with the desired signal. Very little can be done about this latter so-called "ambient" noise, so it imposes a limit on the effective sensitivity of the receiver. It is not likely, for example, that the receiver will reproduce a 1-uv signal very well when the incoming noise is itself 2 or 3 uv!

While noise which is caused by the car's electrical or ignition system also places a limit on the weakest signal that can be successfully reproduced, something can be done about it--it can be suppressed.

Noise suppression requirements and procedures vary considerably for different vehicles and with different types of installations, the location and use of the system often determining what degree of noise suppression is required. Where the system has a lot of reserve, so that the signal at each of the receivers is high, it may not be necessary to provide much suppression; the signal may be sufficiently strong to override the noise. Where the vehicle operates in low signal areas, however, it is necessary to limit the noise to a level lower than that of the signal, if contact is to be assured. One factor limiting the amount of noise suppression which should be realized for this condition is the ambient noise; it would be useless to reduce vehicle noise to a level far below that of the ambient noise, for the latter will always limit the reception.

The procedure for suppressing vehicle noise follows two phases. First, there is the general procedure which should be followed in almost all vehicle installations. Second, there are additional steps that must be taken when such routine procedure does not accomplish the desired suppression.

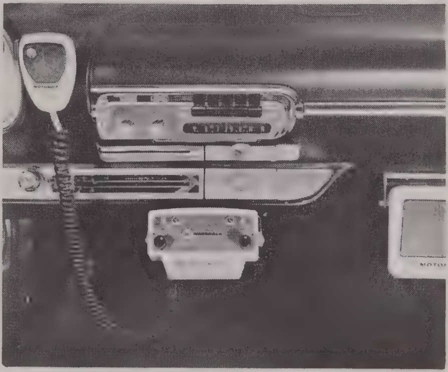
General Noise Suppression Procedure

If the vehicle is not already equipped with noise suppressors, the first thing to do is to install a suppressor in the center lead of the distributor cap and a capacitor at the armature lead of the generator. (Details for the installation of these units are given in the equipment instruction manual.) Most modern cars, have a by-pass capacitor at the generator, and the distributor suppressor alone remains to be installed. These units usually provide sufficient suppression of the ignition and generator noise without causing the radio to lose its ability to reproduce weak signals. Occasionally, the gauges produce some noise. This is suppressed by installing a capacitor at the gauge terminals, under the dash.

Receiver Noise Balance

Although the noise balance of a receiver is not a routine procedure in noise suppression, it is a regular part of the proper installation of the equipment. The noise balance of a receiver depends upon the last IF section being balanced with the response characteristic of the Permakay filter. Otherwise, the discriminator will fail to provide good noise idling and quieting. Before starting, we must assume that the receiver has been properly aligned; noise balancing should never be attempted without proper alignment.

For noise balance, with a signal applied from a signal generator and the motor running, so that noise is also present, the generator is adjusted to the center frequency and set at a level capable of producing about 20 db of quieting. The amount of noise is noted. The generator is then adjusted to either side of resonance and the amount of noise noted. If the zero discriminator output point coincides with the null point of the noise, the receiver is balanced. A perfect noise balance is not always realized, due to variations which may exist. Therefore, as long as the null is within 2 scale divisions of zero, the balance is satisfactory.



This Microphone is Within Easy Reach of the Driver.

With the generator once more at center frequency, the plate tank coil of the first 455-kc IF amplifier is adjusted slightly in either direction, the purpose being to decrease the noise at the speaker. In making this adjustment, it is important that the reading at metering position 2 does not decrease more than 0.5 microampere. If the reading is lower than this amount, the receiver sensitivity will suffer or, at least, the reserve gain will be sacrificed. In some receivers the plate tank of the IF stage will not show any appreciable change in noise balance, because of the loading resistors in the plate tank. With these receivers, it will be necessary to provide the noise balance by means of the tuned circuits in the first IF section.

Locating Noise Sources

After the general procedure for suppressing vehicular noise has been completed and the receiver adjusted for optimum noise balance, the noise input to the receiver may still be too high; further noise suppression may still be desirable. The first thing to do is to locate the source of the noise. Noise may be caused by the generator, the ignition system, the electrical gauges, or by static discharges.

The source of most noises can be determined from the sound heard in the speaker. Ignition noise is characterized by regular popping or snapping sounds, which follow changes in the speed of the engine. The ignition coil, distributor or spark plugs may be the actual source of ignition noise, the interference being radiated from the interconnecting wires.

A whining noise can usually be attributed to the car generator. This kind of noise should also follow changes in the speed of the motor.

Harsh, raspy noise, of a continuous character is usually caused by gauges: the most common offender is the pulsing type of temperature gauge. Popping noises, occurring only when the car is in motion, may be caused by static discharges from insulated parts of the vehicle. Erratic popping, which increases as lights and other electric accessories are turned on, are usually caused by miniature arcs resulting from the small voltages which exist between the vehicle body, frame and motor block.

Be Sure to Avoid the Gas Tank, Gas Line and Similar Parts of a Vehicle when Drilling Holes and Mounting Two-Way Radio Equipment.

Ignition Noise Suppression

The problem of suppressing ignition noise has been growing more acute with the widespread use of 12-volt electrical systems. This high-impulse type of noise is at once the most bothersome to radio reception and the most difficult to eliminate. Some of the more common causes of noise within the ignition system are: Distributor breaker points not operating properly, inefficient ignition condenser, corrosion and poor contacts within the system, and spark plugs improperly spaced or in poor condition.

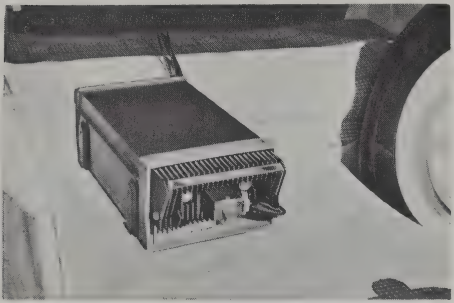
Figure 3 shows several noise suppression arrangements which can be applied to the ignition system. Circuit element 1 represents a 0.1 mfd capacitor inserted across the primary lead of the ignition coil to ground. Either a capacitor such as that supplied with the equipment or a special coaxial type capacitor may be used. (Coaxial capacitors are more effective in reducing severe interference.) This capacitor should be located right at the coil, and the lead to the grounding point should be as short as possible.

Circuit element 2 represents the suppressor mentioned above, placed in the distributor cap lead. This should be located as close as practical to the distributor cap. Circuit elements 1 and 2 are often all that is needed to provide the necessary suppression.

Ignition noise may be further reduced by using circuit elements 3 and 4. In any case, these two components should be tried first, for they are usually the most effective in reducing the noise. When resistance ignition cable (3) is used for greater noise reduction, care must be taken not to introduce too much resistance, thereby sacrificing the performance of the engine. (It is possible to cause rough idling, particularly in cool weather, by using too much resistance.) The resistive type spark plug (4) is often included in the newer cars. The only precaution to be observed here is to make sure that replacement plugs, when used, are of the correct type for the operation of the car and that the "gap" is correct. Many of the new cars have a resistance wire type harness between the coil and the plugs as standard equipment. When this is the case, it may be neither necessary nor helpful to use resistance plugs. Resistance plugs and ignition wires may usually be installed without causing trouble, however, in cars which have the higher ignition voltage.

Spark Plug Leads

Where stubborn ignition problems are encountered and the preceding remedies fail to provide sufficient noise reduction, it would be well to use an ohmmeter to check the continuity of each of the spark plug leads. There must be a path for DC. Where there is no DC path, the end connectors may be checked. If continuity is established by "squeezing" the terminal, the lead itself is probably satisfactory. Where the continuity still is intermittent, it is best to install a replacement lead, checking the new one first for continuity.



In Locating the Housing, Allow Plenty of Room for Servicing Trunk Mount Radios.

A minimum number of terminals should be used within the ignition system. Thus, it would be better to use a resistor-type spark plug or a resistance spark-plug wire than to use a regular spark plug or spark-plug wire and install separate series suppressors. If resistance wire is used, the amount of resistance added is established by the manufacturer of that particular car.

Ignition Noise

Ignition noise is coupled to the surrounding parts and reaches the two-way radio in several ways; one of the most common is direct radiation into the antenna. Resonant lengths of wire are common at high-band frequencies, and these act like a tuned antenna, radiating the available noise power quite efficiently. Ignition noise is also often coupled to low-voltage circuits. Spark plug leads should thus be separated from other wiring. The length of these wires should be changed in such instances. Shielded wire is another possible solution of difficult noise problems if the performance of the vehicle is not to be impaired.

Sometimes the distributor points undergo considerable arcing, and this causes interferences due to radiation from the associated primary wiring. Assuming that suppressors have been already installed in the primary lead and in the lead to the center connector, and that the leads to the spark plugs are all making good contact, the use of a coaxial type suppressor in the primary lead will prove the most effective. If the distributor itself is operating properly, the above steps should provide the necessary noise suppression.

Generator Noise Suppression

Generator noise is characterized by a high-pitched whine which varies with the speed of the generator. This makes its recognition a simple matter; if the noise changes with the speed of the generator, the generator is probably causing it, for there is nothing else in the car which produces this type of sound varying as it does with the motor speed.

Generator noise is usually the result of arcing between dirty or worn brushes and the commutator. In some cases, commutators may be cleaned with fine sandpaper but never with emery cloth. It is advisable to have this service performed by a competent specialist. Most of this noise can be held to a low level by keeping the generator in good operating condition.

Where generator filtering is required, a capacitor connected between the primary lead and a good ground makes an efficient suppressor. Coaxial capacitors are more efficient than ordinary capacitors over the entire noise range and they are universally preferred for maximum possible noise reduction.

Where the noise caused by the generator is unusually severe, a shielded wire, well-grounded at both ends, can be used between the generator and the voltage regulator. Heavy generator noise can also be suppressed by using an elaborate pi-type filter. These filters, which are connected directly at the generator, are usually available from the manufacturer.

Voltage Regulator Noise

Noise caused by the voltage regulator can usually be recognized by its raspy sound, the result of arcing at the regulator contacts. Where this noise is not excessive, filters may be added to the regulator. Otherwise, the best solution may be to install a new regulator! A coaxial capacitor will usually suffice at the lead to the generator, provided that the connection is close to the regulator and provided that the ground is good.

It is not permissible to connect such a capacitor at the generator field terminal of the regulator, for this will greatly reduce the useful life of the regulator. Instead, a small 1-watt resistor of about 3.3 ohms must be placed in series with the capacitor, as shown in figure 3. The capacitor will be considerably smaller than the others (usually about .002 mfd) and the resistor must be of the carbon type, not wirewound. It is usually unnecessary to use a capacitor at

Noise Produced by Ignition Systems Often Interferes with Mobile Two-Way Radio Communications.

the battery terminal of the regulator, although this may be advisable if it improves the noise level.

Gauge and Other Equipment Noise

Gauge noise is usually identified by a hissing or crackling sound in the speaker. In most instances the offending unit can be located by jarring the individual gauges while the ignition is on. Noisy gauges should be bypassed as near the noise source as possible, but it is also important to provide a good ground. Connecting wires which are close to the motor block provide a convenient ground point. The oil sender, with its low-pitched clicking sound, and the temperature gauge are among the commonest sources of gauge noise.

Noise is an inherent property of all moving parts which are ungrounded, or insulated from the rest of the vehicle. This includes the wheels, the front wheels in particular, for these are often insulated from the ground by wheel grease. The accumulated static charge produces arcs, which cause noise in the radio equipment. Standard ground brushes and springs will usually reduce the noise from this source.

While most parts of the vehicle are bonded in order to provide a good ground return, occasionally some part of the car body exhibits poor conductivity and becomes a source of noise radiation.

The muffler and tail pipe assembly, for example, is often insulated from the car frame and it may be necessary to ground the tail pipe at several points between the motor and the rear of the vehicle. The hood, too, is often insulated from the car frame, requiring bonding by heavy copper braid and contact wipers.

Although the motor is already grounded to the car frame, it sometime becomes necessary to provide additional ground straps at each corner of the motor. This is particularly true where the ignition noise is too high to be corrected entirely by the methods described above.[3]

Preventive Maintenance

Preventive maintenance, the practice of anticipating trouble and avoiding it before it starts, is a practical method of minimizing repair expense and "outage" time.

A comprehensive preventive maintenance program, when properly undertaken, will more than pay for itself and benefit both the user of the equipment and the service technician performing the maintenance.

The following case history illustrates the value of preventive maintenance.

A new two-way system has been properly installed and checked for

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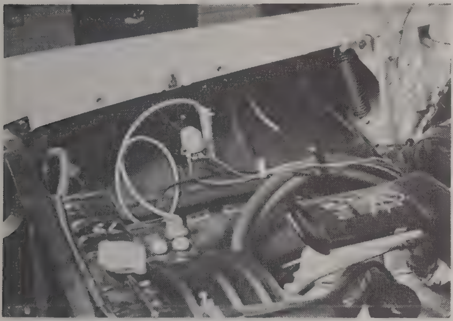
[3] See "Suppression of Ignition Noise in Mobile Equipment," reference M-8B.



Here We See the "A" Relay and Fuse Block Mounted on the Fender Panel, near the Battery

normal operation and it is now up to the serviceman to maintain the equipment. Because the equipment is new and everything is working satisfactorily, the system will probably give months of satisfactory and normal service.

Eventually, however, complaints begin. Weak signals formerly received are no longer being heard, reception has become distorted, etc. The serviceman, on checking the system, cannot find any particular fault which is causing the trouble, so he adjusts the transmitter deviation and frequency until the system seems to have been restored to its normal condition--at least, the messages get through! The same trouble starts again. However, this time the complaints start sooner and they are more frequent.

The answer, of course, is that the serviceman has failed to check the entire system, and to maintain each transmitter, receiver and power supply at or near its normal performance. The power output of the transmitters gradually decreases due to tube aging; the sensitivity of the receivers also suffers, for the same reason, and the output from the power supplies decreases due to worn-out vibrators.

The failure of the serviceman to keep the equipment in normal operating condition forces him to perform a lot of extra work and he is constantly answering emergency service calls. It is also likely to produce an undesirable reaction on the owner of the equipment. He loses confidence both in the serviceman and in the manufacturer. Moreover, if he knows of other systems of the same make and type that give good service, he may readily see for himself that the serviceman is derelict in his duty, that he is actually falling down on the job. This owner of the equipment in the above example is actually losing money. He loses the advantage of having his two-way system in operation when it is needed; moreover, his cars and trucks are being tied up unnecessarily for service.[4]

Sources of Trouble

A good way to start is by analyzing the various sources of trouble. But first we must be able to recognize all the possible sources of trouble that can exist within the system. These, together with their accessories, include (1) the primary power circuit, (2) the receiver, transmitter, power supply and control head including the microphone and speaker, (3) the intercabling between the units and (4) the antenna system.

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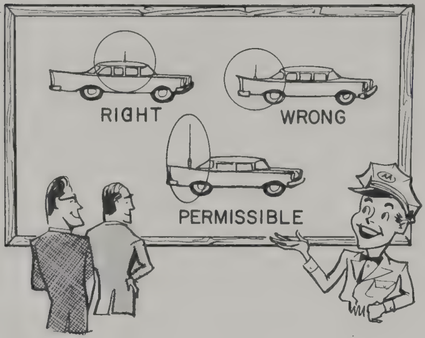
[4] See "System Maintenance of Two-Way Radio," reference M-8C.



Wherever Possible the Mobile Antenna Should be on the Roof Top. Long (Lo Band) Antennas may be Mounted on a Fender if Necessary.

Primary Circuit

Under this head we must consider the various types of primary power commonly encountered in operating the equipment. The battery and generator system in the mobile vehicle is often a source of trouble. Where the battery of the vehicle furnishes the power to operate the equipment, we must remember that poor power output from the transmitter and poor receiver sensitivity may be due to trouble in the primary power source. The best test of a battery is probably the terminal voltage for a specific current drain (load). Commercial testers for checking batteries are available, but a battery usually gives plenty of warning when it is on its last legs. Batteries seldom fail all at once; they usually undergo several periods of abuse before they fail completely.

An old worn-down, or undercharged battery will measure no more than 6 (or 12) volts at the terminals and even less at the radio equipment. Depending upon the current taken by the equipment and the resistance of the cabling components, the voltage at the radio will be 0.5 to 0.7 volt lower than at the battery terminals. If the voltage drop between the battery and the radio is excessive, the reason may be found in a poor connection at the fuse block, relay, or ground connection, or the cable itself may be defective.

Relay contacts often become defective and require service or replacement. Fuses may not make proper contact in their holders, or they may develop high internal resistance. (A maximum drop of 0.1 volt is all that should be encountered across the fuse assembly.) Connections may loosen as a result of vibration and must be tightened or resoldered, whichever applies. Fuse contacts may become corroded, or loosen because of vibration.

In 12-volt systems certain conditions may cause the operating voltage at the radio during standby operation to be well above a safe value, resulting in premature failures within the equipment. Where these high voltages are noted it may be well to install a

Motorola primary voltage regulator such as that discussed in the lesson dealing with power supplies.

Receiver, Transmitter, Power Supply and Control Head

Most of the trouble shooting performed in 2-way equipment seems to be within the receiver and transmitter--possibly because the majority of troubles are found in these units (the receiver and transmitter in particular).

In the receiver, the sensitivity may become poor, its frequency may change, the squelch may be inoperative; a great many other troubles are possible. The most common faults in the transmitter are lack of power, off-frequency operation, and either too much or too little deviation. The most common trouble encountered in the power supply is a decrease in output voltage. While this usually resolves itself into a defective vibrator or inefficient rectifier. Other possibilities, such as a low primary source, for example, must never be overlooked.

Intercabling

Intercabling faults are most common where the equipment is subjected to considerable vibration. (Plugs sometimes become loose or connectors may develop a poor contact.) Cables may also rub against some sharp corner and produce a break or a short. A careful check of all cables and connectors is a must.[5]

The Antenna

Antenna systems are an often overlooked source of trouble. Broken antenna rods, shorted transmission lines, misoriented directional antennas, water-logged connectors, all constitute an enemy to normal operation of both the receiver and the transmitter.

How Often?

The question as to how often a system should undergo a routine check depends upon the type of equipment, its use, and the type of vehicle. Where the equipment is in continuous use and where it is installed in heavy trucks which are subject to a lot of vibration, it is likely to require close attention; a monthly checkup is certainly warranted. On the other hand, some installations may be put to only a limited use in a given period, in which case monthly inspections may not be required. In general, it would be reasonable to say that all units should be inspected after each 500-700 hours of operation. Of course, the FCC requires all transmitters to be checked at least once every six months for proper frequency, deviation and power.

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[5] See "On Locating Intermittants," reference M-8D.

How Are Monthly Checks Made?

For convenience we will refer to all preventive maintenance checks as monthly checks, for in most instances this will be the prevailing period. The question is to determine what this check consists of--how is it performed? In general, the procedure is threefold: listening, visual inspection, and meter measurements.

By listening to the receiver output the trained technician can often spot a defect. The sound may be weak or distorted, or the noise may be weak when the receiver squelch is open. With experience, the normal signal level at certain locations becomes known, and immediate comparisons can be made. Noisy reception, "hash" in the background, and similar effects also indicate improper operation.

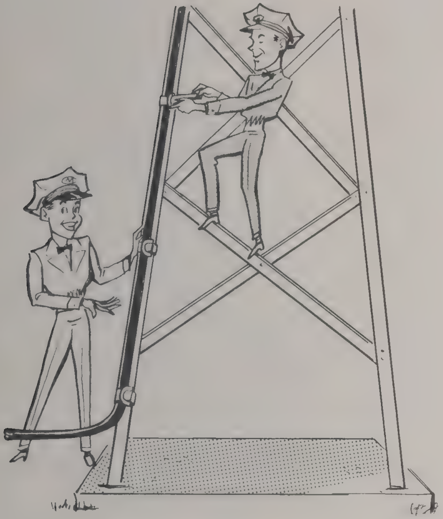
Loose bolts, screws, and clamps, worn cables and mike cords, burned out pilot lamps, and relay arcing, are among the many things which can be located by means of visual inspection. Trouble can also be anticipated by visual inspection. It is quite possible, for example, that a loose plug or connector may not be a source of present trouble, and the equipment may not operate any better after a connector has been tightened; however, the loose connector could eventually be a source of intermittent trouble and might even result in damage to the equipment.

The visual inspection must also include searching for dirt--dirty contacts at relays, dirty or worn dynamotor brushes, corroded fuse holders, and the like. Cracked insulators and tubes operating "red-hot" are also located by means of visual inspection.

Visual inspection also includes what might be called "touch" inspection. Used with caution, the fingers make good detectors of improper temperature, both high and low. Fuses and fuse holders having poor contacts are readily located by the sense of touch. Transformers, relay coils and other units can also be checked by the fingers for overheating. A crystal holder and heater assembly which is cold, or a tube that normally should be warm but isn't, can be detected by "feel."

Caution must be exercised, however, for certain units (tubes and high-wattage resistors in particular) may be too hot to touch without burning one's fingers. Care must be taken that the high voltage circuits are not touched. For this reason the power should first be turned off. (Most components will retain their heat for some time afterward.)

Meter readings are perhaps the greatest aid for evaluating the operation of the receiver and the transmitter. They can be quickly taken, and they give an immediate idea of receiver sensitivity and transmitter power output. Moreover, with the base station signal



In Base Station Installations the Transmission Line Must be Well Secured to the Tower.

coming into the receiver (assuming the transmitter frequency is correct), the netting of the receiver frequency to that of the base transmitter can be effected immediately by this means. Netting means that all the units within one system are placed on the same frequency.

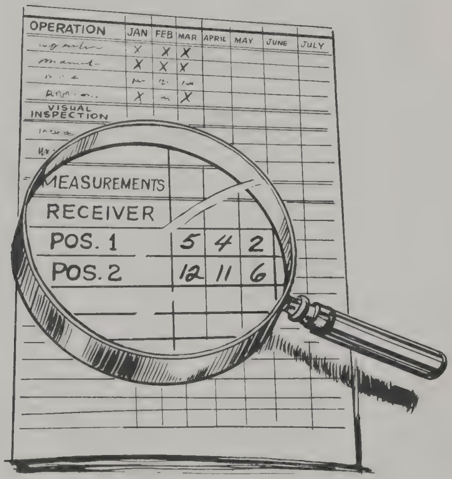
A frequency monitor, a deviation indicator, and a wattmeter can be used to measure the frequency, deviation, and power output of the transmitter; voltmeter readings at the battery and at the input to the equipment indicate the condition of the primary power source. Because the transmitter and receiver both depend upon the supply voltages for normal operation, these voltages must be included in the routine check. The power supply voltages can be conveniently determined by the use of meters.

Specific Checks to Make-- Check List

Figure 4 shows a check list which can be used when making monthly inspections. (The procedures listed are those which have been previously discussed.) This list applies to mobile units only. For base station installations, certain changes would have to be made in the list. The specific items thus vary from system to system, depending upon the service, the nature of the equipment or other factors, but this is not important. What is important is that certain physical and electrical aspects of the equipment are inspected systematically.

While the length of this list seems to be rather formidable at first glance, the complete check can be completed in 30 minutes by a competent technician. This is assuming, of course, that no great amount of service work or trouble shooting is involved. The list need not be followed in a definite sequence. It may be desirable to take the meter measurements and net the frequency of both the receiver and the transmitter before performing the operational check. Or, if the operational check is performed first and any adjustments are made on the equipment, a final operational check should then be made.

No check list is intended to be an absolute must for each inspection. In systems where the audio quality is good, for example, it may not be necessary to check the amount of deviation every month nor will a frequency adjustment be required if the receiver frequency is closely netted to that of the base transmitter. (This check is made by merely observing the meter reading at position 4 with the base carrier applied.)



A Record of Routine Meter Readings Allows the Serviceman to Correct Minor Troubles, thereby Avoiding "Outages" and Expensive Repair Costs.

Off-frequency operation of some of the equipment is often a prime cause of poor system performance. Hence, for the purpose of maximum system operation, it is important to keep the system netted. Without system netting, full advantage of the system cannot be realized or maintained. System netting is even more essential to narrow-band (split-channel) operation.

Routine observation of transmitter deviation also pays off in continued good performance, for full advantage of FM communication cannot be realized where the system is either underdeviated or overdeviated. A word of warning in this matter is apropos at this point. It is almost never necessary to change the setting of the deviation control at the transmitter. If the deviation is not correct, the serviceman should find out why it has changed and correct the trouble at the source, rather than compensating for this trouble by operating the deviation control. To do so may correct the transmission for the time being but it will not correct the original fault, and future trouble may be expected.

The advantage to the serviceman in making and recording these checks will be evident from the following example. Let us suppose that the reading at the grid of the final stage in the transmitter (position 6 on the meter) shows a gradual decrease over a period of several months. The individual decrease for any one month may not be great enough to require attention, but after several months it becomes too low to be disregarded. By having a record of this gradual decrease, the serviceman immediately knows that this should be checked carefully, for if the drive to the final becomes too low, the tube may be damaged. By maintaining the grid drive at the required level, the life of the final amplifier tube is increased and in this manner its premature replacement is avoided.

Besides saving his own time, the serviceman who keeps a record such as shown in figure 4 will be in possession of a valuable tool for maintaining satisfactory relations with his customers. For one thing, the serviceman will find it convenient at some time or another to haul out these records and show the customer just how well his equipment is being watched. Where the customer is paying a fixed amount every month for each unit being serviced, he may have been wondering just what he was getting for his money. Without such a check list it may be difficult to convince certain individuals that they are spending their money wisely. The fact that you, the serviceman, maintain such a record and that you can tell the customer exactly what you have done to each of his units each month immediately classifies you as a businessman who takes care of his job in the proper manner.

Moreover, when you send your monthly bill to your customer, it is well to enclose a summary showing the various parts that have been used and the troubles that were found (and corrected) in each unit.

But we haven't mentioned the greatest advantage of all. By promptly correcting the trouble in a unit when it is not up to par, many breakdowns in the equipment are avoided; the customer gets the maximum use of his radio equipment and the amount of time lost in tying up the vehicles while the radio is being fixed is minimized. This is probably the greatest factor of all to use in selling your services to the customer.

Schedule Monthly Checks

All monthly checks should be performed on a scheduled basis--a particular day of the month should be reserved for checking the equipment for a particular customer. This again is good practice in the eyes of the customer. He is more likely to be satisfied with this arrangement, for he can schedule his vehicles accordingly. In the absence of such a schedule, you may find yourself wasting valuable time waiting for several hours to check a vehicle that is in use. Besides wasting time in waiting to service the vehicle, you leave a bad impression on the customer. Again, if you happen to catch a certain vehicle for a few minutes and start your inspection, it may be called into service right in the middle of the job. The only alternative is to wait until the car returns--more time wasted.

Much time is saved by having a definite checking schedule for each vehicle; and the entire operation becomes more efficient. Certainly more units will be checked in a given time, compared to the number that can be checked when you have to wait until the vehicles are available. Moreover, if various test instruments have been set up for these checks, it is obviously more efficient to check the complete vehicle at one time. Where only half of it can be checked, the serviceman must get these instruments ready again at another time, in order to test the rest of the units.

Base Station Checks

The tests prescribed in figure 4 apply particularly to mobile equipment; several additional checks must be performed at base stations, especially if the base station is remotely controlled. At a base station, we seldom have the problem of low primary power to contend with but there is always the problem of voltage regulation. Poor regulation of the AC source can seriously affect the operation of the equipment. It is also important to make periodic checks of standby equipment (when such equipment is provided) in order to make sure that it will operate as required in case of power failure.

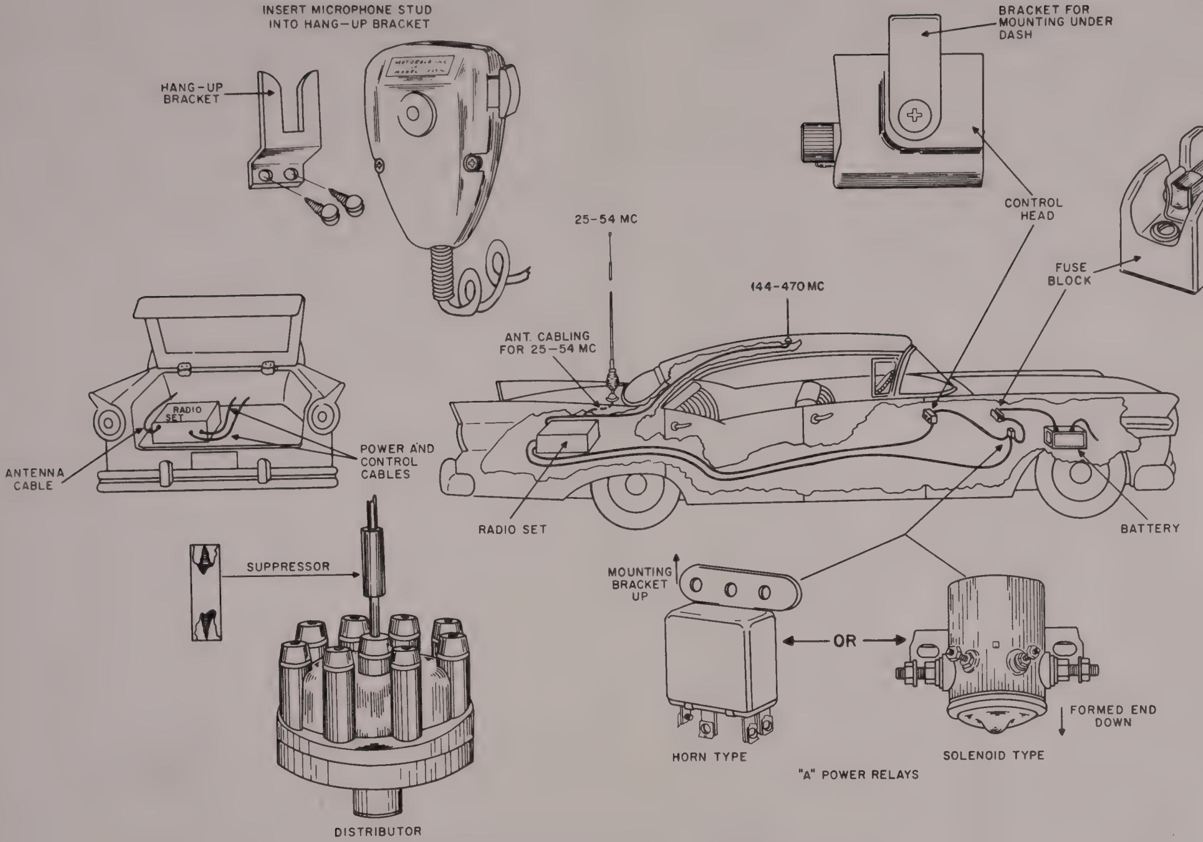
Where base station antennas are mounted on towers, lights may be required and they must be checked. (The FCC has issued rigid regulations on this subject which must be followed.) Where remote control is used, proper line voltages are a must. This is true whether the controlling voltages are required to switch frequencies or to establish the level of the modulating signal. Line levels, hum balance, and other adjustments should be checked periodically.

The specific tests to be made on a given base station installation will depend on the equipment being used. The specific factors to be checked each month may be determined from the instruction manual and a chart prepared accordingly. This chart not only becomes a handy device but, with proper notations added, it will satisfy the FCC regulation requiring that a log be kept on all service and adjustments of the base transmitter. The chart must be kept at the base station and be available for inspection at all times.

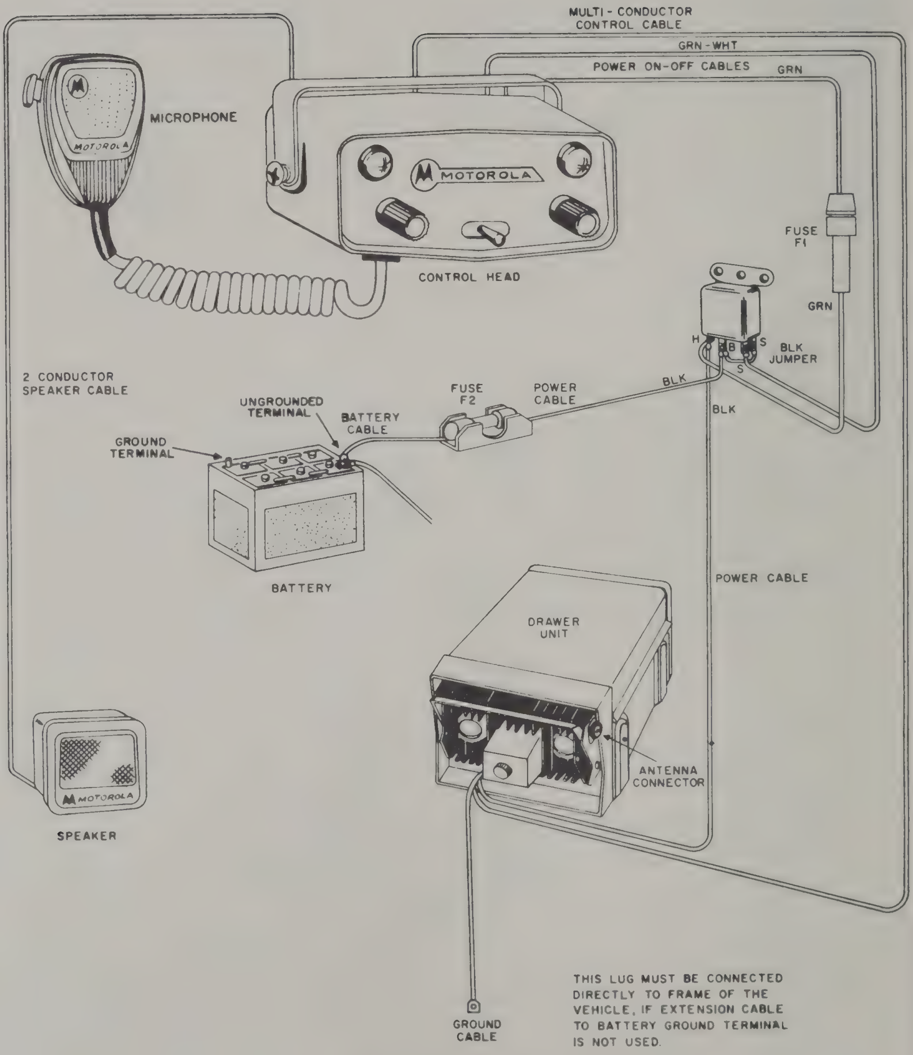
Specialized Equipment

Certain specialized equipment (such as the Motorola Private Line, Quik-Call, etc.) requires additional tests. Again, the specific checks will depend on the equipment and the application to which it is put. The variations are too numerous to list here, but details will be found in the appropriate service manuals.

STUDENT NOTES

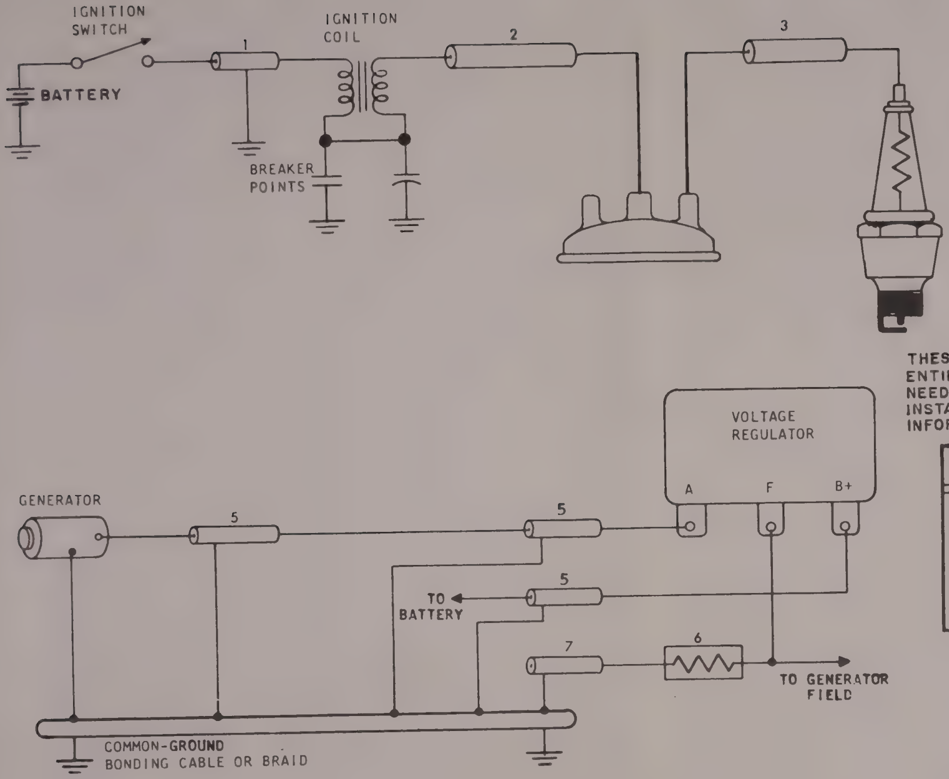


MOBILE REAR MOUNT INSTALLATION DETAIL
FIGURE 1



REAR MOUNT MOBILE CABLING DETAIL
FIGURE 2

STUDENT NOTES



THESE REMEDIES MAY BE USED IN ITS ENTIRETY OR IN PART, ACCORDING TO THE NEEDS OR LIMITATIONS OF THE INDIVIDUAL INSTALLATION. (SEE TEXT FOR COMPLETE INFORMATION.)

REF. SYM.	DESCRIPTION
1.	COAXIAL CAPACITOR, 0.1 MF.
2.	SUPPRESSOR CABLE
3.	RESISTIVE WIRE
4.	RESISTOR SPARK PLUG
5.	COAXIAL CAPACITOR, 0.5 MF.
6.	CARBON RESISTOR, 3.3 OHMS, 1W
7.	BY-PASS CAPACITOR, .002 MF.

TYPICAL NOISE SUPPRESSION DETAIL
FIGURE 3

MONTHLY INSPECTION CHART

MOBILE 2-WAY RADIO

SYSTEM ____________ UNIT# ____________

1) OPERATION	JANUARY	FEBRUARY	4) MEASUREMENTS	JANUARY	FEBRUARY
Receiver Squelch	X		Receiver		
Receiver Volume	X		Test Set Position 1	5	
Audio Output	Normal		2	12	
Reception	Normal		-4	+1	
Mike Button	X		5	28	
Contact to Base	Report Normal		6	24	
Contact to Others	Weak to Mobile #2		(Vol & Sq Clockwise) 8	15	
Contact on Freq #2	X		20-db Quieting	.5 uv	
2) VISUAL INSP.			B Supply	190 V	
Green Light	X		Receiver Netted to Base	X	
Red Light	X		Noise Idling	-1	
Mike Connector	X		Transmitter		
"A" Power Relay Connections	X		Test Set Position 2	22	
Fuse Contacts	X		3	13	
Battery Connection	X		-4	8	
Power Plug at Unit	X		5	16	
Ground Terminal	X		6	11	
Control Head	X		(B+ times 20) 7	340 V.	
Unit Mounting	X		(A supply X 0.3) 8	6 V.	
Antenna Mounting			Motor Idling		
Antenna Connector			PA	25	
3) TOUCH CHEEKS			Frequency Netted	X	
Rec. Crystal Warm	X		Deviation Check	X	
Trans. Crystal Warm	X		Mike Output	X	
Transformers Normal	X		Power Output	25 Watts	

Check Conducted By: E.M.
Date: JAN. 4/58

FIGURE 4

national
MOTOROLA
RADIO COMMUNICATIONS
service